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An Introduction to Energy Conservation in Residential Development

Research Report

December 1983

Canada

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

AN INTRODUCTION TO ENERGY CONSERVATION IN RESIDENTIAL DEVELOPMENT

Prepared for Canada Mortgage and Housing Corporation

and the Department of Energy, Mines and Resources

by

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ABSTRACT

This report is intended as a guide to practical energy savings in the urban living environment for planners, architects, landscape architects, developers, builders, and public officials, as well as the general public. Various methods of conserving energy in residential areas are considered with emphasis on those which are cost-effective in that they have positive economic returns.

The focus is on the principles of energy conservation as they apply to residential development. Approximately 35 per cent of the energy consumed in a typical Canadian city is associated with residential development including space heating and cooling, water heating, lighting, appliances, and other basic uses. Transportation, which is closely related to the location and layout of residential areas, consumes a further 25 per cent of the urban energy budget.

Canadian energy zones are discussed in the context of the Canadian and world energy situations and the potential for reducing conventional energy use. A Canada Energy Zone Map is described and regional examples of energy requirements and opportunities are outlined.

Major approaches to energy conservation at the city, neighbourhood, and residence scales of residential development are considered. Each level has different sets of energy concerns and different sets of actors who most influence energy conservation. Principles of conservation are outlined, and examples presented to indicate their costs and benefits in various situations.

This study was conducted by Underwood McLellan Ltd. for Canada Mortgage and Housing Corporation and the Department of Energy, Mines and Resources. The analysis, interpretations, and recommendations are those of the consultants and do not necessarily reflect the views of the Corporation or the Department.

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PREFACE

Canada Mortgage and Housing Corporation and the Department of Energy, Mines and Resources, Canada are actively encouraging the conservation of energy in the residential sector. To this end, a number of initiatives are underway to study the problems associated with conservation, to develop options for saving energy, and to demonstrate cost-effective methods of conserving energy.

This report represents the results of one study sponsored by the two federal agencies, that examines the possibilities of saving energy in residential developments. It focusses on the larger-scale planning issues at the level of the city and neighbourhood design, but also touches upon techniques for conserving energy in the residence itself and in its siting on the lot. The costs and benefits of a variety of energy conserving techniques are examined on the basis of the best available data. Techniques and combinations of complementary actions are recommended where they prove to have a short-term positive payback. Other options that appear to be beneficial in the longer term are also included. It deals with both new and existing development and is sensitive to the various conditions of the different regions of the country.

Underwood McLellan Ltd., who undertook the study, indicate that there is a paucity of accurate quantitative data on this topic, and that it is difficult to carry out comparative financial evaluations of alternative conservation options. The report includes, therefore, qualitative descriptions as well as more rigorous analyses. Canadian experience in the are of planning and energy conservation is limited, hence US examples are used in a number of situations.

CMHC and EMR intend that this report be used by planners, designers and land use regulators as an aid to the development of energy-conserving neighbourhoods.

CHAPTER 1

ENERGY OVERVIEW

Canada, although facing problems in the availability and price of oil, is favourably endowed with most other conventional and alternative energy resources. As a net exporter of energy -- coal, natural gas, uranium, and hydro-electricity -- this country has the wherewithal to achieve energy self-sufficiency through oil substitution and energy conservation, and, at the same time, to develop alternative sources for enduring energy security. This requires investment in oil substitution and energy conservation as well as development of renewable energies. Energy conservation has the potential to save large amounts of energy in Canada with positive economic and social benefits.

The potential for energy self-sufficiency in Canada shows regional imbalances: the three Western Provinces each have a surplus whereas the rest of the country is either energy dependent or has an energy deficit. Although this picture is changing as resources are developed in the North and East, imbalances in energy potential will likely remain. The potential for alternative energy exploitation also varies according to climate and geography.

Despite regional variations which affect energy prices, the energy expenditures of most Canadians in similar income groups are comparable, but differ between income groups in the same region. Government programs may be required to help those who are unable to afford increased energy prices and who have already invested to their limits in energy conservation.

WORLD ENERGY PROBLEM

The world energy problem is really one of oil availability and price. Between 1960 and 1980, world oil consumption tripled and the relative use of oil compared to other energy sources doubled to meet two-fifths of world primary energy demand. This growth, coupled with a decline in the capacity of the United States to supply, placed a heavy burden on other world oil suppliers.

World oil prices declined steadily from the 1940s until the 1960s and remained stable at approximately $3.00 per barrel until the early 1970s, despite moderate inflation. After 1973, the cartel of the Organization of Petroleum Exporting Countries (OPEC) replaced the multi-national oil companies as the main force in world oil production. World prices rose beyond $38.00 per barrel in 1980, producing a major economic crisis.

Oil importing countries are moving to reduce their dependence on oil but the change will not be easy. Careful choices are required regarding the use of other conventional energy sources; for example, heavy reliance on coal or nuclear power increases concerns for environment, safety, and health. Alternative energies are not yet sufficiently developed to play a major role and, although conservation efforts are proceeding, major reductions in energy consumption will take time, for behaviour patterns and industrial structures based on inexpensive and plentiful energy must be modified.

CANADIAN ENERGY PROSPECTUS

Canada, although dependent on imported oil since 1976, produces enough energy in other forms, such as hydro-electricity and natural gas, to displace all oil imports and still have substantial resources for export (Figure 1).

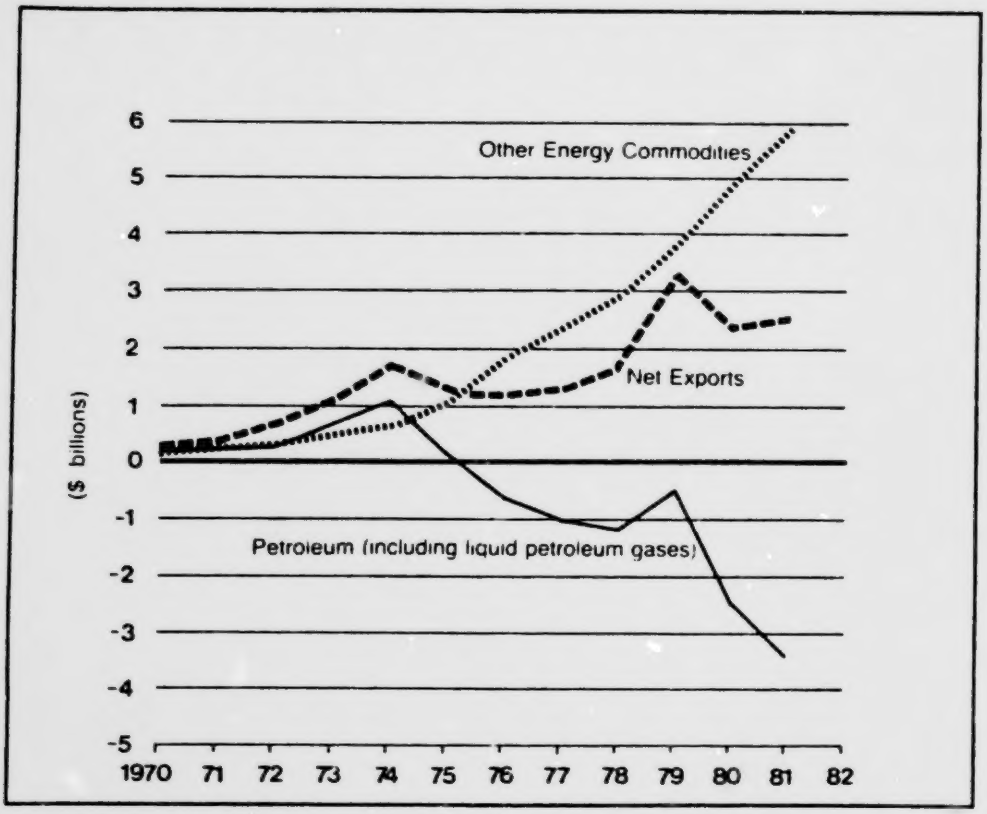
The National Energy Program 1980

Oil substitution and energy conservation are the cornerstones of a national energy strategy aimed at a rapid reduction of reliance on oil and a gradual conversion to alternative energy systems (Figures 2 and 3). This strategy, the National Energy Program 1980 (NEP), should lead to energy self-sufficiency and security of energy supplies. NEP recommends improving oil-use efficiency; using surpluses of electricity, natural gas, and other fuels to overcome the deficit in oil in the coming decades; developing the conservation resources; and developing alternative energy sources through biomass, solar, wind, geothermal, tidal, and nuclear fusion technologies.

Improving oil-use efficiency means the replacement of heavy fuel oil in industrial applications and the upgrading of heavy oil stocks to lighter products such as gasoline, aviation fuel, diesel fuel, home heating oil, and petroleum feedstocks. This involves the modification of existing refineries and the development of new refineries to reduce to a technical minimum the production of heavy fuel oil in Canada.

Federal grants are being offered to consumers to substitute heating oil with natural gas or electricity. The NEP goal is independence from the world oil market by 1990.

Figure 1. Canadian trade balance in energy commodities (Energy, Mines and Resources; The National Energy Program Update, 1982).



Source: Statistics Canada, Exports—Merchandise Trade, Annual, Cat 65-202, and Imports—Merchandise Trade, Annual Cat. 65-203.

- Statistics Canada includes in the definition category "uranium elements and isotopes," items with both energy and non-energy uses. Rather than attempt a breakdown between uses, the entire group has been excluded for purposes of this table. Had they been included, they would have raised the net trade balance by $657 million, or to $3,059 million, in 1981.

Figure 2. Canadian energy sources. (Energy, Mines and Resources, 1980).

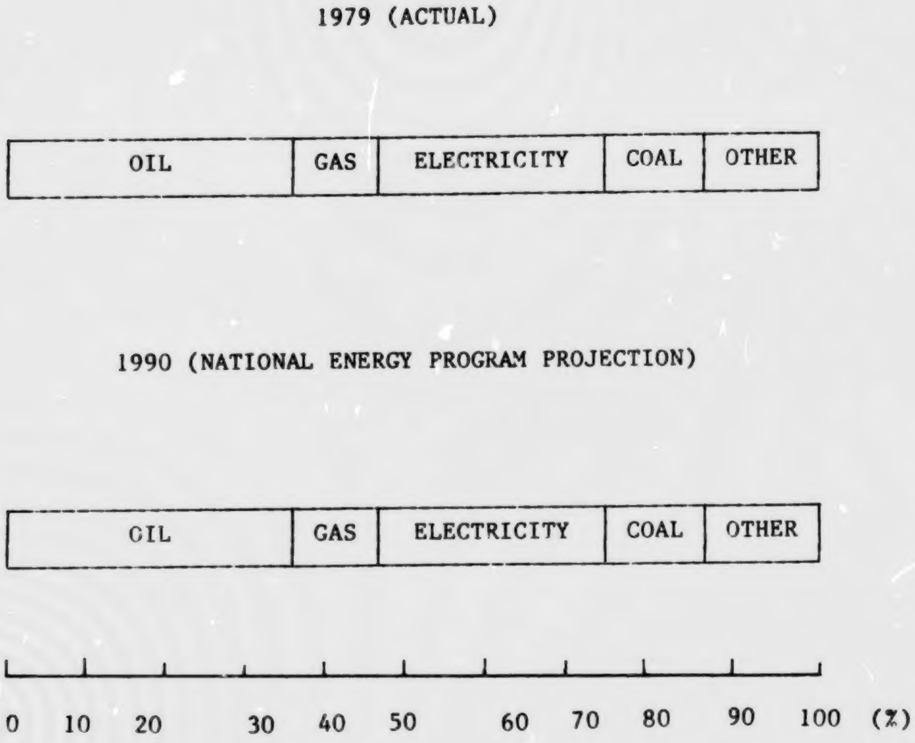
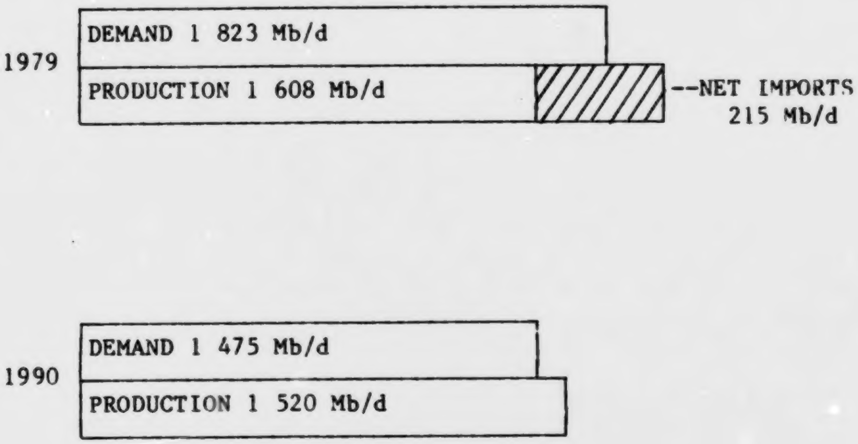


Figure 3. Canadian oil supply and demand (Energy, Mines and Resources, 1980).



Natural gas prices are being allowed to rise more slowly than the price of oil, remaining at a level of 75 per cent or less of the oil price, in order to encourage conversion. Distribution systems for natural gas will be expanded to Vancouver Island and the Atlantic Provinces, and East coast gas prices will match those in Ontario and Quebec.

Paradoxically, past inefficiencies because of traditionally inexpensive energy mean Canada now has a substantial potential to conserve energy which can be easily and economically exploited.

The implementation of most energy-conserving measures depends on the economics of the required investment. As the price of energy increases relative to other goods and services, more measures will become economical and those which are now viable will have shorter pay-back periods.

Energy conservation has the following major economic and social benefits, even where the implementation of conservation measures are not immediately cost-effective. First, conservation can have a substantial impact on reducing the national demand for energy. The Federal Government promotes conservation programs because they represent the most immediate and inexpensive means to self-sufficiency. Even convincing Canadians to turn down thermostats, turn off lights, and drive smaller cars will produce substantial savings in energy. Secondly, conservation can reduce Canada's reliance on oil. Thirdly, conservation can create jobs and new opportunities for small businesses, and the benefits would be broadly distributed across the country. Fourthly, conservation and alternative energy technologies can assist in maintaining environmental quality in contrast to the effects of the extraction and use of fossil fuels, and the environmental degradation associated with hydro projects. Lastly, conservation can buy time, allowing Canada to stretch fossil fuel supplies and prepare for a lower-consumption lifestyle based on the use of alternative energy sources.

Canada's alternative energy strategy is to develop an inexhaustible, environmentally benign and flexible energy system controlled by Canadians and recognizing regional diversity. Energy will be derived from renewable resources including hydro-electricity, solar radiation, wind, biomass, geothermal and tidal power, and nuclear fusion.

Oil will continue to play an important role in Canada's energy mix for a considerable time, since this country already has the infrastructure for oil production, distribution, and consumption.

END USE

Of the total energy used in Canada, approximately 33 per cent is used in the industrial sector, 25 per cent for transportation, 20 per cent in residential areas, 12 per cent in the commercial sector and 10 per cent in the supply of energy itself. Although residential energy use as a percentage of all urban energy use varies between cities depending on their climate, industrial mix, and form, Canadian residential energy consumption is typically 35 per cent of the total for the urban sector (Figure 4). Of that total approximately 75 per cent goes toward space heating, 15 per cent toward water heating, and 10 per cent toward other basic uses such as lighting and appliances.

Differences in energy consumption between average residential households in different cities are not as pronounced as would be expected given the variation in climatic, economic, geographic, and other factors. This is due, in part, to Federal Government equalization of fuel energy costs, especially in the Atlantic Provinces, but also there seems to be a certain accepted level of energy expenditure for home heating which is similar from one end of Canada to the other.

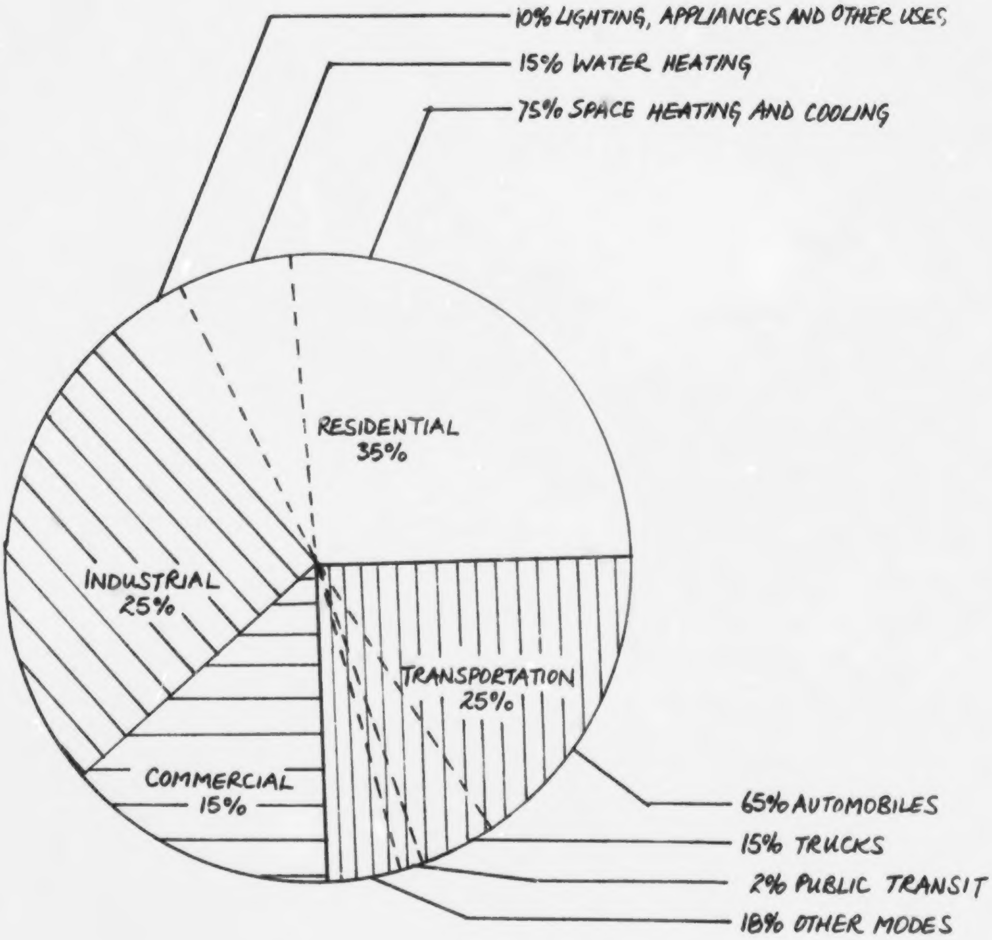
Lifestyles and Energy Use

Individual lifestyles in society affect the general pattern of energy use. The "Baby Boom" age cohort, a large bulge in the population profile of Canada, entered the high-consumption age group of 15 to 30 years in the 1970s. This group, which had expectations of high living standards and an interest in present consumption, caused an increase in energy use per capita.

Although attitudes are not easily changed, increasing costs of energy tend to modify trends in its consumption. Energy-saving home features are becoming important to home buyers today as compared to the appeal of traditional new home amenities (Land Use Digest, 1981). Asked to rate the importance buyers place on a variety of features, builders ranked the following as extremely important: attic insulation (67%); wall insulation (63%); kitchen appliances (49%); storm windows (43%); and central air conditioning (42%). Kitchen appliances and central air conditioning, long regarded as the most popular features in new homes have now been replaced by attic and wall insulation.

In a survey of homeowners, brokers, and appraisers (Land Use Digest, 1981), 83 per cent of the homeowners, 66 per cent of the brokers, and 78 per cent of the appraisers responding said well-insulated houses were worth more at resale. Brokers estimated that a well-insulated home would be worth an average of 9 per cent extra and appraisers estimated that it would have a resale

Figure 4. Energy consumption in a typical Canadian city.



bonus of 5 per cent, so energy conservation in housing has become a marketable asset.

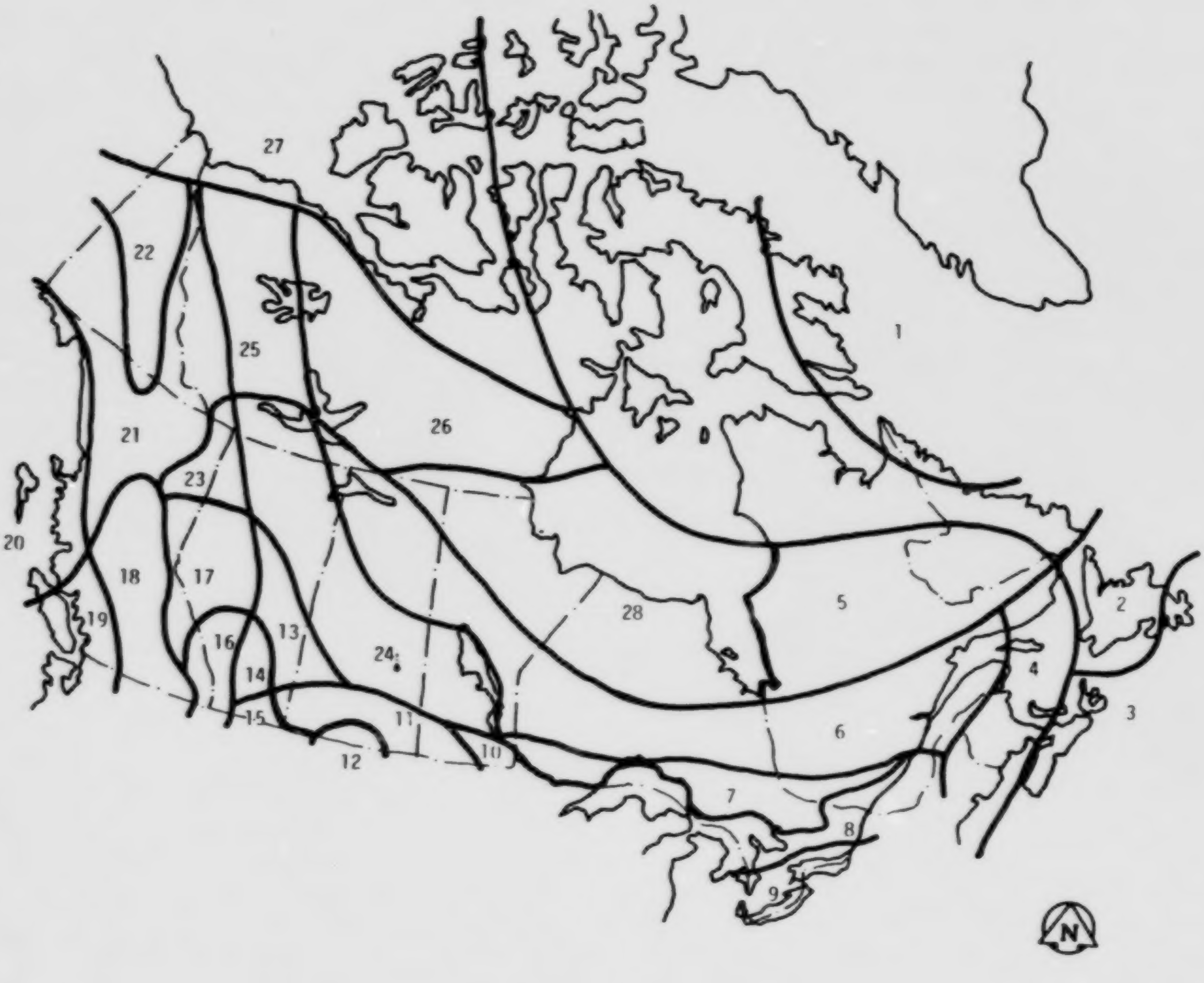
According to Miloff (1980), the lifestyles of some Canadians are already changing to reflect the need to conserve energy. Lifestyle changes among low-income families and senior citizens have sometimes reduced their levels of energy consumption to very small absolute amounts. Further rises in energy prices would not induce greater cutbacks but only greater hardship. Most affected by energy price increases are senior citizens in energy-inefficient homes, low-income tenants in bulk-metered housing, and large families with greater-than-average requirements for space heating, water heating, and transportation.

Whereas higher-income families appear to have invested more heavily than lower-income families in conservation measures to reduce residential space-heating requirements, Miloff says that the real difference between income groups is only slight when bulk-metered low-income tenants are omitted. Bulk-metered households have the least ability to control their heating expenditures and the least incentive to cut back on energy use, since they do not have immediate positive feedback through lower energy bills. Low-income families who are not bulk-metered generally spend larger proportions of their incomes on energy conservation than higher-income families. They are more likely than higher-income groups to have added insulation blankets or reduced temperature settings on hot water tanks.

CANADIAN ENERGY ZONES

The wide range of energy requirements, opportunities for alternative energy sources, and constraints to conservation in Canada must be understood so that those energy systems and energy-conserving measures least expensive and most appropriate will be developed in every region of the country. A systematic approach to regional energy use and conservation would help reduce the burden of energy expenditures on all income groups.

In Canada, 28 energy zones can be differentiated by their climate, geography, energy supply, and their potential for different energy sources (Map 1 and Table 1). The map provides a systematic indication of energy requirements and energy source opportunities in each zone, and serves as a guide to the use of appropriate alternative energy sources and energy-conserving measures in different regions of Canada. This information will permit planners in the public and private sectors to use or encourage the use of energy conservation measures and energy sources which are most appropriate to their local context.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Map 1. CANADIAN ENERGY ZONES

The energy zones are regions with similar climate, geography, energy supply, and energy potential, indicating energy demand and opportunities and constraints in each region.

Table 1. Key to the Canadian Energy Zones Map, describing parameters of climate and alternative energy sources.

Energy zone	Physiographic region/climate	Existing energy supply	Future energy sources	Potential for future energy
1. Eastern Arctic/Labrador	Canadian Shield: ARCTIC	- imported oil dependent	- off-shore oil and gas: - wind:	MEDIUM HIGH
2. Newfoundland	Appalachian Highlands: COLD	- imported oil dependent	- off-shore oil and gas: - wind: - biomass: - solar:	MEDIUM HIGH MEDIUM VERY LOW
3. Avalon Peninsula/ Nova Scotia	Appalachian Highlands: COOL	- imported oil dependent - coal - future natural gas pipeline	- off-shore oil and gas: - coal: - wind: - biomass: - tidal: - solar:	MEDIUM MEDIUM-HIGH HIGH HIGH HIGH LOW-MEDIUM
4. New Brunswick/ Gulf of St. Lawrence	Appalachian Highlands: COOL	- imported oil for electricity - diverse energy base - future natural gas pipeline - nuclear development	- coal: - hydro: - biomass: - solar: - wind:	MEDIUM LOW HIGH LOW-MEDIUM LOW
5. Northern Quebec/ Labrador	Canadian Shield: ARCTIC	- imported/external oil dependent - hydro-electric	- hydro: - wind: - biomass: - solar:	HIGH LOW LOW VERY LOW
6. Mid-Canada	Canadian Shield: VERY COLD	- imported/external oil dependent - hydro-electric	- hydro: - biomass: - solar:	HIGH MEDIUM-HIGH MEDIUM
7. Southern Canadian Shield	Canadian Shield: COOL	- imported/external oil dependent - hydro-electric - nuclear sites	- hydro: - biomass: - solar: - wind:	MEDIUM VERY HIGH MEDIUM LOW

Table 1. Continued.

Energy zone	Physiographic region/climate	Existing energy supply	Future energy sources	Potential for future energy
8. Central Canada	Great Lakes - St. Lawrence Lowland: COOL	- imported/external oil dependent - natural gas pipeline - some hydro-electric - nuclear sites	- air-to-air heat pumps: - biomass: - solar:	MEDIUM VERY HIGH MEDIUM
9. South Central Canada	Great Lakes - St. Lawrence Lowland: MODERATE	- imported/external oil dependent - natural gas pipeline - some hydro-electric - nuclear sites	- air-to-air heat pumps: - biomass: - solar:	HIGH VERY HIGH HIGH
10. South-eastern Manitoba	Prairie: COLD	- external oil dependent - gas pipeline - some hydro-electric	- biomass: - solar: - wind:	VERY HIGH MEDIUM-HIGH LOW
11. Southern Prairie	Prairie: COLD	- virtually self-sufficient in oil and gas - coal	- oil and gas: - coal: - biomass: - solar: - wind:	HIGH MEDIUM VERY HIGH HIGH MEDIUM-HIGH
12. South Saskatchewan	Prairie: COLD	- virtually self-sufficient in oil and gas - coal	- oil and gas: - coal: - biomass: - solar: - wind: - geothermal:	HIGH MEDIUM VERY HIGH HIGH MEDIUM-HIGH MEDIUM
13. North Central Prairie	Prairie: COLD	- major exporter of oil and gas - coal exporter	- oil and gas: - biomass: - solar:	HIGH VERY HIGH LOW-MEDIUM
14. Northern Badlands	Prairie: COLD	- major exporter of oil and gas - coal exporter	- oil and gas: - coal: - solar:	HIGH HIGH MEDIUM-HIGH

Table 1. Continued.

Energy zone	Physiographic region/climate	Existing energy supply	Future energy sources	Potential for future energy
15. Southern Badlands	Prairie: COLD	- major exporter of oil and gas - coal exporter	- oil and gas: - coal: - solar: - wind:	HIGH MEDIUM HIGH MEDIUM-HIGH
16. Southern Foothills/ Rockies	Cordillera: COOL	- major exporter of oil and gas - coal exporter	- oil and gas: - coal: - solar: - geothermal:	HIGH HIGH MEDIUM-VERY HIGH MEDIUM
17. Northern Prairie	Cordillera/ Prairie: COLD	- major exporter of oil and gas - coal exporter	- oil and gas: - coal: - biomass: - solar: - geothermal:	HIGH HIGH VERY HIGH MEDIUM-LOW MEDIUM
18. Central Mountains	Cordillera: MODERATE-COLD	- diversified energy base: oil and gas, coal, hydro-electric	- hydro-electric - coal: - biomass: - geothermal: - solar: - wind:	HIGH LOW HIGH HIGH MEDIUM-LOW LOW-MEDIUM
19. Southern West Coast	Cordillera: MODERATE	- diversified energy base: oil and gas, coal, hydro-electric	- hydro-electric - coal: - air-to-air het pumps: - biomass: - geothermal: - solar:	MEDIUM LOW MEDIUM HIGH HIGH HIGH LOW
20. Northern West Coast	Cordillera: MODERATE-COLD	- diversified energy base: oil and gas, coal, hydro-electric	- hydro-electric: - oil and gas: - coal: - geothermal: - tidal: - biomass: - wind:	HIGH MEDIUM LOW HIGH HIGH LOW LOW

Table 1. Continued.

Energy zone	Physiographic region/climate	Existing energy supply	Future energy sources	Potential for future energy
21. Northwest Mountains	Cordillera: VERY COLD	- diversified energy base: some oil and gas, coal, hydro-electric - some imported oil	- hydro-electric:	HIGH
			- coal:	LOW
			- geothermal:	MEDIUM
			- biomass:	LOW
			- wind:	LOW
22. Central Yukon	Cordillera: ARCTIC	- hydro-electric - imported oil dependent	- hydro-electric:	MEDIUM
			- coal:	LOW
			- geothermal:	MEDIUM
			- wind:	LOW
23. Peace River	Cordillera: ARCTIC	- major exporter oil and gas - coal exporter - hydro-electric	- oil and gas:	HIGH
			- coal:	HIGH
			- hydro-electric:	MEDIUM
			- geothermal:	MEDIUM
			- biomass:	MEDIUM-HIGH
			- solar:	LOW
24. Parkland	Prairie: VERY COLD	- self-sufficient, exporter of oil and gas - some coal	- oil and gas:	HIGH
			- coal:	LOW
			- biomass:	HIGH
			- solar:	LOW-MEDIUM
25. Mackenzie River Lowlands	Mackenzie Valley Lowlands: ARCTIC	- imported oil dependent	- oil and gas:	MEDIUM
			- biomass:	LOW
26. Northwest Territories	Canadian Shield: ARCTIC	- imported oil dependent	- hydro-electric:	MEDIUM
27. Western Arctic	Shield and Lowlands: POLAR	- imported oil dependent	- oil and gas exploration:	HIGH
			- wind:	LOW
28. Hudson Bay	Canadian Shield and Hudson Bay Lowlands: ARCTIC	- imported oil dependent - hydro-electric	- hydro-electric:	HIGH
			- oil and gas exploration:	MEDIUM
			- coal:	LOW
			- solar:	LOW
			- wind:	LOW

Climate and Energy Requirements

Local climatic factors largely determine residential energy requirements and effective conservation measures. Canada's climate has large differences ranging from the Atlantic Provinces, with cold winters, mild summers, and moderately high precipitation throughout the year; through Southern Ontario, with hot summers due to the invasion of tropical air masses; across the Prairie Provinces with cold winters, hot summers, and moderate-to-little precipitation; to the West Coast with moderate temperatures and high precipitation all year. The northern areas of the Provinces and the southern areas of the Territories have long cold winters and short mild summers; whereas northern areas of the Territories have very cold winters, cool summers, and extremely dry climates.

Mean Annual Heating Degree Days

In order to generalize Canadian climatic regions and to more easily consider examples from the United States in the context of Canadian climate, a descriptive system based on mean annual heating degree days is used to differentiate between energy zones in terms of climate and heating requirements. This does not account for humidity, however, which influences the perception of "cold" and "hot" at different temperatures.

The heating requirements of the zones are assessed in terms of heating degree days, which is the difference, in degrees Celsius, between the mean temperature for that day and an 18°C base temperature (the outdoor temperature below which auxiliary heating is assumed to be required). For example, when the mean temperature for a winter day is -5°C, 23 heating degree days will be accumulated for that day. Mean annual heating degree days are the total heating degree days through the year.

The outdoor temperature at which auxiliary space heating would be required in low-energy housing typically ranges from -10°C to 10°C, depending on factors such as solar gain, internal gain, and heat loss through the envelope. Although traditional heating degree days cannot be used to calculate heating loads on low-energy houses, they do provide a rough comparative measure of heating requirements in different parts of Canada. This, in turn, influences the design of low-energy housing in the different zones.

Heating Requirements and Energy Expenditure

The map descriptions of heating requirements range from LOW to VERY HIGH, corresponding to climates from MODERATE to POLAR (Table 2).

Heating requirements are only one of a number of factors affecting annual household energy expenditure. Regina, Saskatchewan, with nearly double the mean annual heating degree days of Vancouver, British Columbia, has a lower average energy expenditure per household, although the mean daily January temperature in Regina is -15°C and in Vancouver is -2.5°C. Lower energy prices and different building standards for insulation and windows are among the factors in Regina's favour. The largest annual energy expenditure per household is in St. John's, Newfoundland, which has less than 5 000 heating degree days (COOL), and the smallest is in Edmonton, Alberta, with approximately 6 000 heating degree days (COLD).

Table 2

Climatic zones for Canadian cities based on heating requirements

Climate	Annual heating requirements (heating degree days)	City or Town
MODERATE	3000 - 4000	Windsor, Ontario Vancouver, British Columbia
COOL	4000 - 5000	St. John's, Newfoundland Halifax, Nova Scotia Fredericton, New Brunswick Montreal, Quebec Toronto, Ontario Nelson, British Columbia
COLD	5000 - 6000	Winnipeg, Manitoba Regina, Saskatchewan Calgary, Alberta Edmonton, Alberta
VERY COLD	6000 - 7000	Saskatoon, Saskatchewan Whitehorse, Yukon Territory
ARCTIC	7000 - 8000	Yellowknife, Northwest Territories
POLAR	9000 - 12000	Inuvik, Northwest Territories

Summer Cooling Loads

Summer cooling loads also effect annual household energy expenditure. The indicator of humidity, the humidex, determined by taking the dry bulb temperature and adding a fraction of the vapour pressure, is an important variable in assessing requirements for air-conditioning. Winnipeg, with a mean daily temperature in July similar to Toronto and Montreal, has less requirement for air conditioning than the eastern cities due to the drier Prairie climate.

Urban Microclimates

Large metropolitan centres tend to modify the regional climate, decreasing heating requirements in winter but increasing cooling requirements in summer (Figure 5). Urban microclimates are related to factors such as lower albedo (the amount of sunlight reflected from surfaces rather than absorbed), lower wind speed, and higher runoff co-efficient.

Use of the Energy Zones Map

The Energy Zone Map can be used to compare the opportunities and constraints of different energy zones, allowing an example of energy conservation in one zone to be considered in the context of other zones. Table 1 provides the qualitative and quantitative parameters for the descriptions of climate and energy potential. The Saskatchewan Energy Showcase Homes, with high insulation values and solar features, can be used as an example of how this works. Since Saskatoon is in Zone 24, Parkland, with a VERY COLD climate and LOW to MEDIUM solar potential, the Energy Showcase Homes should fit the climate and solar potential of Zone 6, Mid-Canada, and Zone 17 Northern Prairie, which have characteristics similar to Zone 24 (see Table 1). They will also fit most COOL to COLD climates with MEDIUM to HIGH solar potential but would be overdesigned for a MODERATE zone and inappropriate for a zone with no solar potential.

Conventional Energy Sources and Potential

About half of Canada's energy requirements are supplied by hydrocarbons (crude oil and natural gas), but whereas the three Western Provinces are net exporters of hydrocarbons, the remainder of the country relies heavily on imports (Figure 6). Alberta alone is self-sufficient in oil. Eastern and Northern Canada depend on imported oil for fuel and electricity, and, although both regions have future energy potential, both have immediate supply problems.

Figure 5. Heat island in Winnipeg showing temperature deviations associated with urban microclimate (Royal Architectural Institute of Canada, 1979)

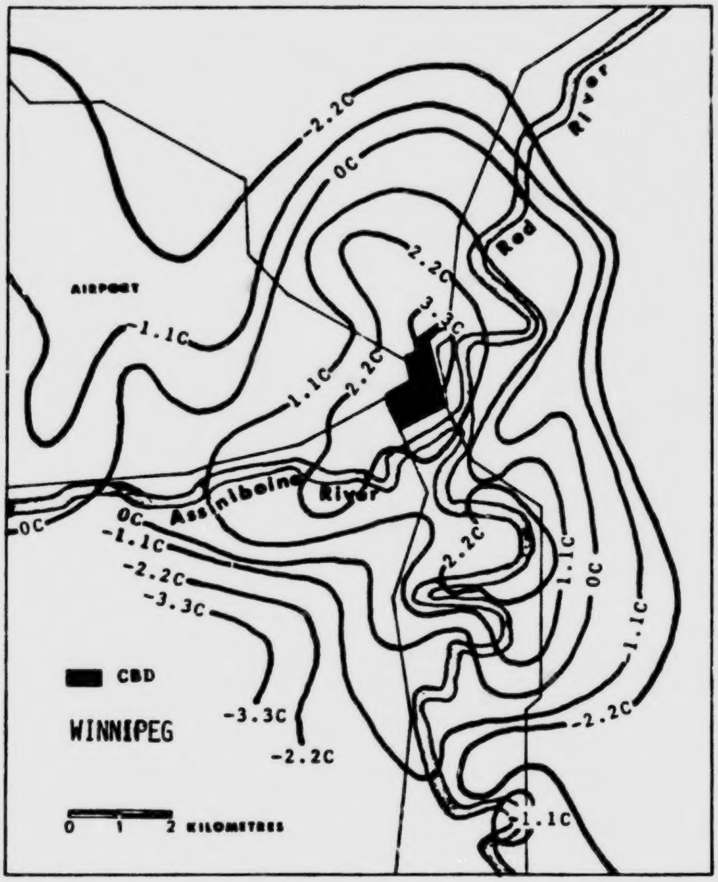
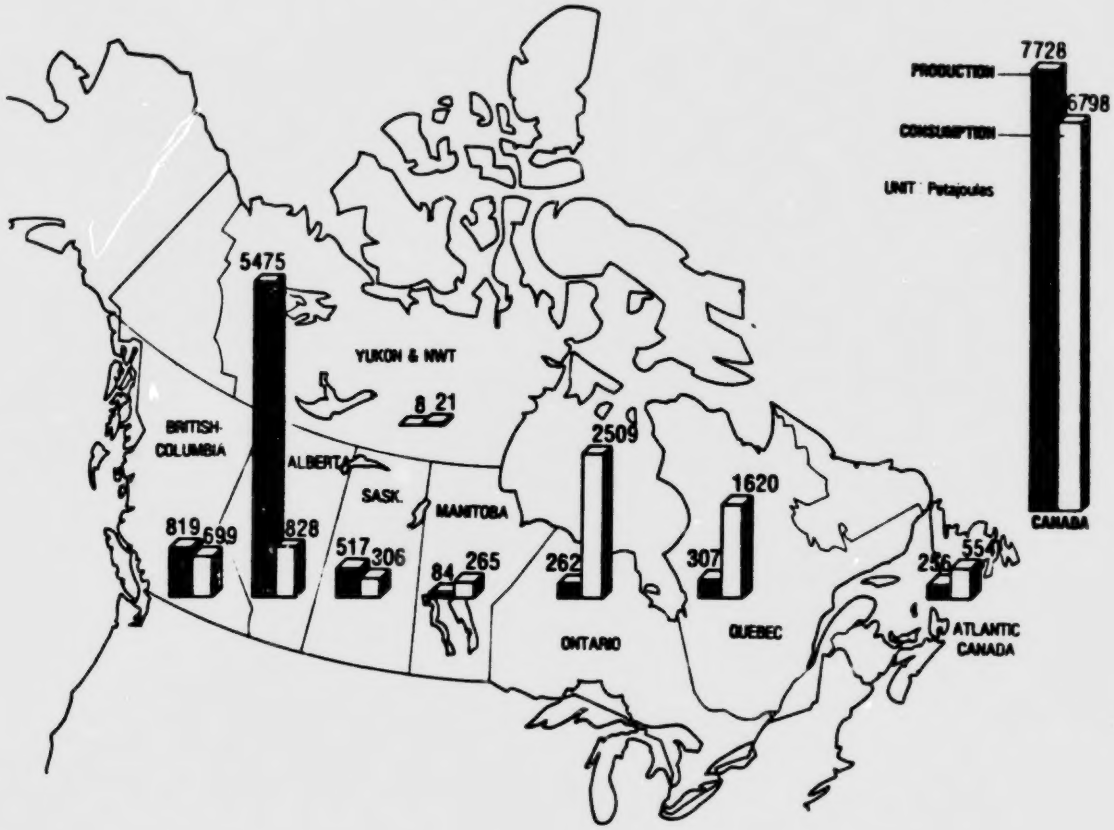

-2.2C
0C
2.2C
3.3C
AIRPORT
-1.1C
-1.1C
2.2C
Red
River
Assiniboine
River
0C
0C
-1.1C
-2.2C
-3.3C
2.2C
1.1C
0C
-1.1C
-2.2C
CBD
WINNIPEG
-3.3C
-2.2C
1.1C
0
1
2 KILOMETRES

Figure 6. Primary energy production and net energy consumption by region in Canada during 1978 (Statistics Canada, 1980).


PRODUCTION
CONSUMPTION
UNIT: Petajoules
7728
6798
CANADA
YUKON & NWT
8
21
BRITISH-COLUMBIA
819
699
ALBERTA
5475
828
SASK.
517
306
MANITOBA
84
265
ONTARIO
262
2509
QUEBEC
307
1620
ATLANTIC CANADA
256
554

Note: Data for Newfoundland, New Brunswick, Nova Scotia and Prince Edward Island are aggregated as Atlantic Canada for reasons of confidentiality in industry reporting. Energy statistics for the Yukon and Northwest Territories are also aggregated. Otherwise the regional breakdown is by province.

The potential in each energy zone is described for conventional energy sources such as oil and gas, coal, uranium, and hydro-electricity. The potential for air-to-air heat pumps is also described. These HIGH, MEDIUM, or LOW levels are based on qualitative parameters set out in Table 1. Generally, the levels are as follows:

HIGH:	refers to a significant resource with widespread exploitation in the energy zone;
MEDIUM:	refers to a less significant resource or a zone of major resource exploration; and
LOW:	refers to a zone with potential for an energy resource, or with minor exploitation of a resource.

Alternative Energy Sources and Potential

The potential to exploit alternative energies varies substantially from region to region. Alternative energy strategies must be more highly tailored to specific zones of the country than the past conventional energy policies. Eastern and Northern Canada have pressing claims for attention.

Projects using alternative energy sources are underway across the nation, and include passive solar design in subdivisions from the Atlantic Provinces to British Columbia; developing vertical axis wind power systems for the Magdalene Islands and the Arctic; using biomass for district heating and power production in Montreal and Toronto; developing a geothermal power plant at Meager Creek, British Columbia; and developing the Bay of Fundy tidal power.

Ontario is seeking to increase energy self-sufficiency from about 10 to 35 per cent by 1995 using uranium, coal, and peat fuels, and alternative energy sources such as solar, wind, and biomass; in addition to hydro-electric power. Other provinces also have energy strategies to best use available conventional and alternative energy sources.

The potential in each energy zone is described for alternative energy sources, including solar, biomass, geothermal, and tidal. These HIGH, MEDIUM, or LOW levels are based on quantitative parameters set out in Table 1.

Solar Energy Potential

Solar energy potential in an energy zone is measured in terms of annual mean daily solar radiation expressed in Langleys, a Langley being equivalent to 11.6 watt-hours/m^2/day. Across the most heavily populated parts of Canada the solar radiation over the year averages about 300 Langleys per day. This means that one square metre of horizontal solar collector would receive about 3.5 to 4.0 kilowatt-hours of radiant energy per day in this region. (This can be compared to one litre of heating fuel which delivers about 10kW.h of energy). Only a portion of this energy is captured by passive solar systems.

Canada compares favourably with most countries of the world in terms of average solar radiation received, but this average value is less important than the seasonal distribution of solar energy.

The majority of solar energy is received during the long, sunny, summer days and the peak in energy supply is, thus, opposite to that of space heating demand. Seasonal thermal storage is both costly and inefficient. This should not be taken as an indication that solar energy will have a negligible role to play in those applications which are best matched to the availability of the resource.

Wind Energy Potential

Wind energy potential in an energy zone is measured in terms of annual average wind energy density at 50 metres above the ground, expressed in watts per square metre. The areas in Canada with the best wind regimes are the eastern Arctic, Atlantic Canada, northern Ontario and Quebec, the southern Prairies, and parts of British Columbia. Coastal British Columbia is one of the areas of greatest wind energy potential and in its mountainous parts there are many sites where winds are funnelled in a way which makes them ideally suited for power generation.

Biomass Energy Potential

Biomass energy potential in an energy zone is measured by biomass productivity expressed in tonnes per hectare per year. This does not account for resource quality, however, or the ability to harvest or transport biomass.

Geothermal Energy Potential

Geothermal energy potential in an energy zone is expressed qualitatively according to the existence of volcanic belts or thermal springs, or areas where the natural heat of the earth close to the surface is above 80°C. Zones of HIGH potential are found in the areas of geologically recent volcanism in British Columbia and the Yukon. Zones of MEDIUM potential are found in areas of the sedimentary basin underlying the Prairie Provinces, where enough useful energy might be recovered to offset the recovery costs.

Tidal Energy Potential

Tidal energy potential in the energy zone is expressed in terms of the potential for a major tidal power site. Observatory Inlet (near Prince Rupert) and the Bay of Fundy are the only potential sites in Canada.

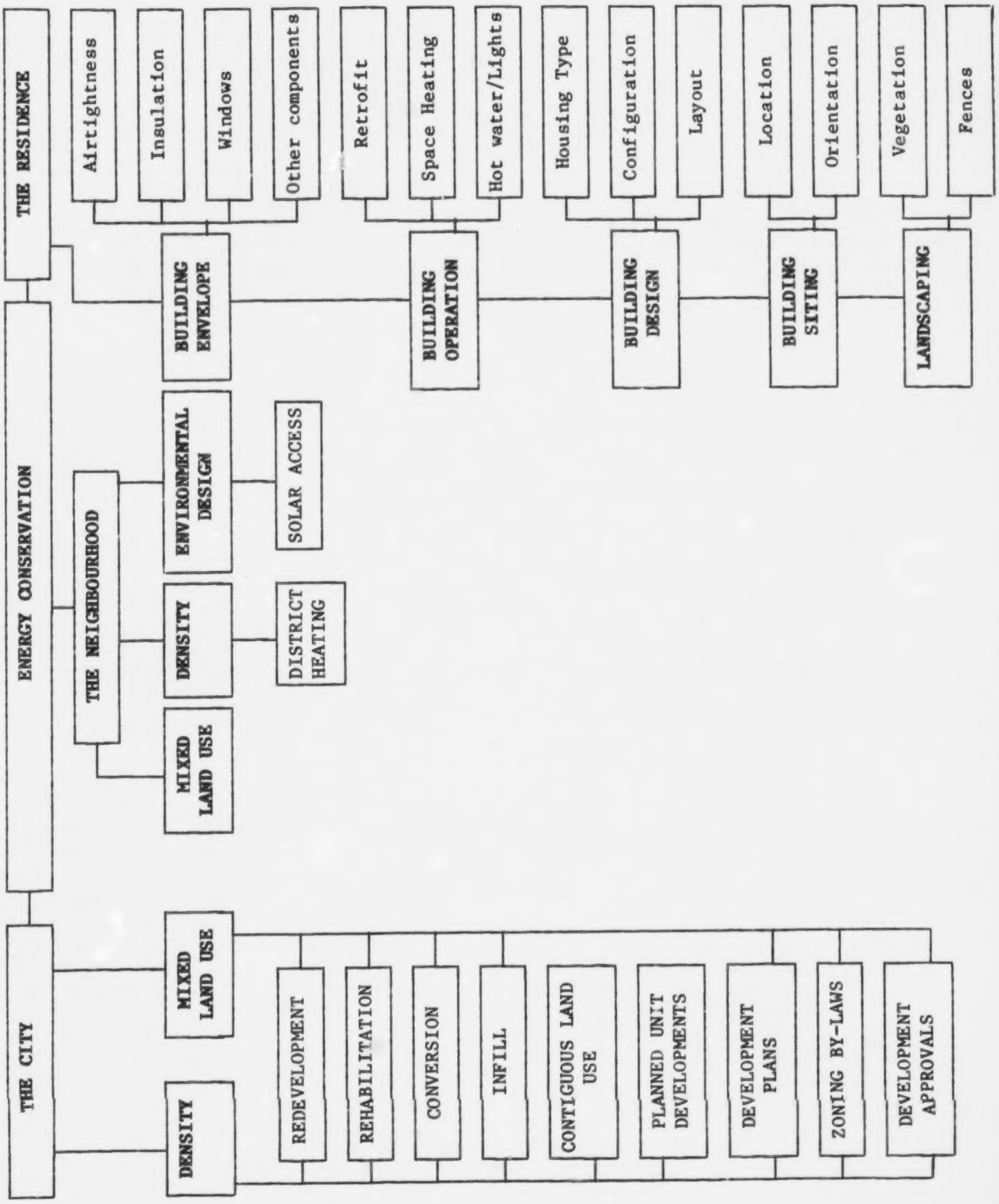
Use of Energy Zones in City, Neighbourhood, and Residential Planning and Design

Mapping energy zones is a systematic approach to energy use and conservation which can be used as a guide to regional decisions on oil substitution, energy conservation, and the development of alternative energy technologies. Three levels of residential land use -- the city, the neighbourhood, and the residence -- serve to separate the principal conservation issues into manageable groupings, each with a major point of focus (Figure 7). The city and neighbourhood levels deal with the organization of land uses to produce energy savings, primarily through reductions in embodied energy requirements for roads and utilities, and reductions in operational energy requirements for transportation. The neighbourhood level, also considers the use of environmental design to save embodied energy in land development and house construction and operational energy for space heating and cooling, and the use of district and passive solar heating to reduce conventional energy use. Finally, the residence level covers improvements to the building envelope, operation, design, siting, and landscaping to reduce energy requirements for space heating and cooling. Map 1 can help to illustrate the way in which local energy needs and opportunities relate to city, neighbourhood, and residential planning concerns. To demonstrate its use, three different energy zones are examined.

Zone 1., Eastern Arctic/Labrador

The Eastern Arctic/Labrador zone (Frobisher Bay) has an ARCTIC climate with a VERY HIGH heating requirement (6 000 to 12 000 HDD). Even low-energy housing requires substantial additional energy to maintain internal comfort. Low, massive multiple-family buildings are an ideal housing form in this extremely cold, windy environment with very little winter sun. Settlements should be designed for indoor activity although building masses shelter outdoor areas from high winds. Since the sun is only above the horizon for short periods during the winter, the wind, with intensities of 700 to 900 watts per square metre and a HIGH energy potential, is the only readily available alternative source of energy. The use of vertical axis windmills as a source of electricity and heat is being explored in the Eastern Arctic/Labrador zone. District heating has been used in this

Figure 7. Major energy-conservation approaches


ENERGY CONSERVATION
THE CITY
DENSITY
MIXED LAND USE
REDEVELOPMENT
REHABILITATION
CONVERSION
INFILL
CONTIGUOUS LAND USE
PLANNED UNIT DEVELOPMENTS
DEVELOPMENT PLANS
ZONING BY-LAWS
DEVELOPMENT APPROVALS
THE NEIGHBOURHOOD
MIXED LAND USE
DENSITY
DISTRICT HEATING
ENVIRONMENTAL DESIGN
SOLAR ACCESS
THE RESIDENCE
BUILDING ENVELOPE
Airtightness
Insulation
Windows
Other components
BUILDING OPERATION
Retrofit
Space Heating
Hot water/Lights
BUILDING DESIGN
Housing Type
Configuration
Layout
BUILDING SITING
Location
Orientation
LANDSCAPING
Vegetation
Fences

zone with heat being generally transferred along with other services in utilidors. Like buildings, these must be raised above, or insulated from, the ground in permafrost areas. District heating, today, is based on imported oil but, in the future, off-shore oil and gas or uranium from this zone may provide district heat and power through cogeneration.

Zone 9, South Central Canada

South Central Canada (Toronto) has a MODERATE climate (3 000 to 4 000 HDD) with LOW heating requirements. Low-energy housing requires little or no additional heat during the heating season. Present heating requirements for conventional residences are met with imported oil and natural gas, and hydro-electric and nuclear power. These will continue to be important energy sources. In addition, South Central Canada has HIGH potentials for air-to-air heat pumps and solar energy, and a VERY HIGH biomass potential.

Decisions about city and neighbourhood planning in this context depend on residential energy use. Efficient furnaces maintain the competitiveness of natural gas for home heating, while air-to-air heat pumps provide an efficient means of converting electrical energy for both heating and cooling. Passive solar housing may be cost-effective in this energy zone but requires careful planning of neighbourhoods and housing units to ensure optimum efficiency. Like passive solar housing, low-energy housing needs little or no additional heat during the heating season. Combining low-energy and passive solar designs, however, reduces the efficiencies of both and can cause excessive heat build-up on sunny winter days. A variety of energy sources, including garbage and oil, gas, coal, and nuclear energy can be used for cogeneration of power and heat for district heating in this zone.

District heating provides cheap, low-grade heat at reasonable costs for housing which is not thermally efficient. District heating systems affect the form of cities, neighbourhoods, and residences, since they are most effective in conjunction with compact, low-rise development and high thermal densities (large heating requirements per area). Combining district heating with low-energy or solar housing again reduces the cost-effectiveness of both systems. The decision to use a particular residential energy system in this zone should depend on the thermal density (heating requirements per unit area of land) of the development, the availability or potential to exploit the energy source, and the overall cost-effectiveness.

Zone 11, Southern Prairie

The Southern Prairie zone (Regina) has a COLD climate with a HIGH heating requirement. Combining low-energy residential design with a passive solar system may be worthwhile in this zone, especially if the cost of direct-gain passive solar heating is minimal. Care must be taken to reduce the cooling effect of winter winds through neighbourhood planning. The Southern Prairie zone is virtually self-sufficient in coal, oil, and natural gas, giving these energy sources a competitive edge. Natural gas is especially favoured for residential space heating. In compact communities with high thermal densities, district heating based on coal, oil, or natural gas cogeneration is a viable alternative. Biomass only competes with fossil fuels in special cases; for example, near major food processing plants. Similarly, wind energy is only attractive in certain areas as a supplier of mechanical power, electricity, or direct heat. Biomass potential is VERY HIGH and wind potential MEDIUM to HIGH in the Southern Prairie zone, but the current cost of using other fuels for residential space heating is less.

In every energy zone, economics, rather than the energy potential of a conventional or alternative energy source, dictate priorities. As fossil fuels become more scarce and costly, the viability of alternative energy sources will improve. This is already becoming apparent with the development of tidal power in Nova Scotia and geothermal power in British Columbia, the use of wind power in the Northwest Territories, and district heating fuelled by garbage in large urban centres in Ontario and Quebec.

CHAPTER 2

CITY - LEVEL APPROACHES

The most significant variables affecting energy conservation and residential land use at the city level are transportation and urban form. Whereas residential energy consumption is significantly reduced by neighbourhood and residence-level conservation approaches, transportation energy consumption is most affected by city-level approaches (Figure 8). Since more than half the energy expenditure of the average Canadian household is for the family car, reductions in transportation energy use will significantly affect household budgets.

Increasing density and mixing land use will conserve transportation energy by improving public transit efficiency, reducing travel distances, and reducing residential energy use through more energy-efficient building forms. Other approaches which conserve energy in urban transportation include developing major new transportation systems and convincing people to use them, and improving the efficiency of the private car.

TRANSPORTATION AND URBAN FORM

An estimated 20 to 30 per cent of Canada's secondary energy consumption can be attributed to transportation. The automobile alone accounts for 65 per cent of this consumption. Putting this in the context of residential energy use, an Ontario Ministry of Housing study (1981) found that 52 per cent of a household's energy requirements are for the family car (Figure 9).

These figures relate to the key role played by the automobile in past and present Canadian society. Residential development has traditionally centred on the single-family detached house. The affordable automobile provided the means for travelling longer distances to work, shopping, and other activities, enabling cities to expand further into the countryside to meet the housing demand. In the past, public officials in some North American cities promoted suburban development to alleviate congestion resulting from the increased popularity of the automobile. Inexpensive fuel sources supported the car-based lifestyle by keeping travel costs within an affordable range for most segments of society.

Figure 8. Opportunities for energy conservation at the city level

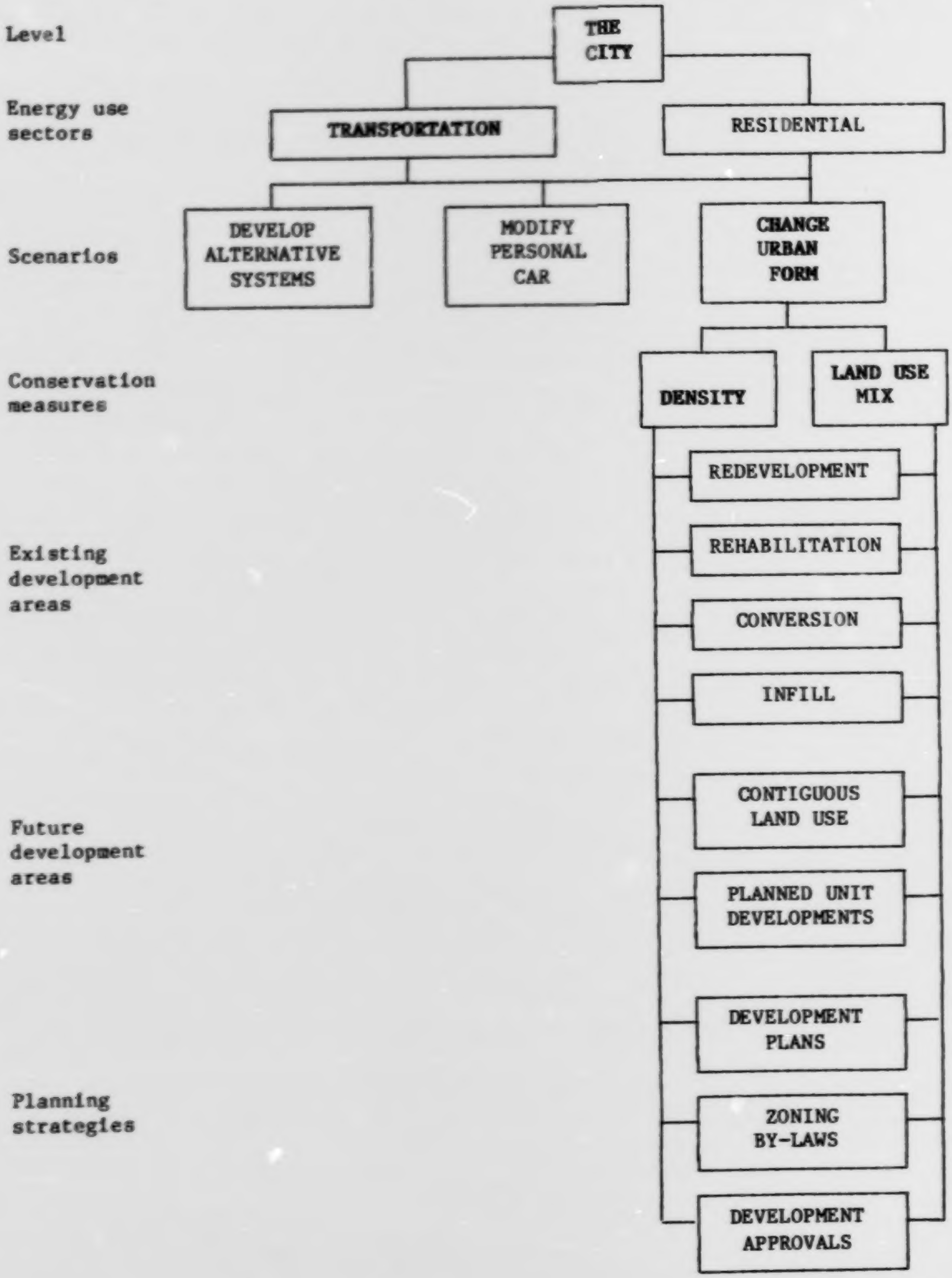
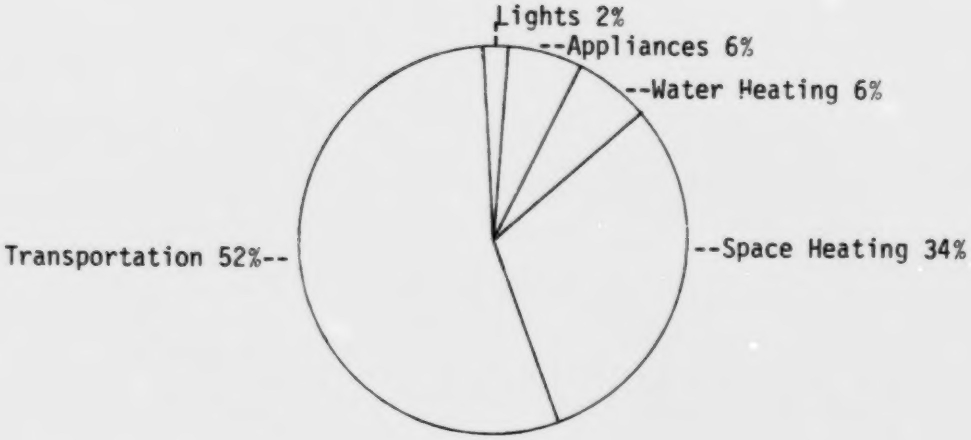

Level
THE CITY
Energy use sectors
TRANSPORTATION
RESIDENTIAL
Scenarios
DEVELOP ALTERNATIVE SYSTEMS
MODIFY PERSONAL CAR
CHANGE URBAN FORM
Conservation measures
DENSITY
LAND USE MIX
Existing development areas
REDEVELOPMENT
REHABILITATION
CONVERSION
INFILL
Future development areas
CONTIGUOUS LAND USE
PLANNED UNIT DEVELOPMENTS
Planning strategies
DEVELOPMENT PLANS
ZONING BY-LAWS
DEVELOPMENT APPROVALS

Figure 9: Household energy use. (Ontario Ministry of Housing, 1979).



The low-density urban form which developed as a result of the private car, single-family detached housing, leap-frogging development, and inexpensive, plentiful energy supplies is best described as "sprawl". Sprawl requires more energy for the construction of buildings, roads, and utilities; more energy for the movement of people, goods, and services; and more energy for the operation and maintenance of roads and utilities, than higher density development. Wilbur Smith and Associates (1980) noted that energy savings as high as 50 per cent can be realized if higher numbers of dwelling units per hectare (du/ha), particularly multi-unit, low-rise structures (67 to 94 du/ha), replaces sprawl.

Transportation energy consumption is primarily associated with urban form and use of the private automobile. The decision to use the personal car was found by Middleton Associates (1979) to be based on factors such as the average trip length, trip frequency, trip energy consumption, and other modes of transportation available. The results confirmed that automobile use is greater in areas further from the Central Business District (CBD) where origins and destinations are more widely dispersed. The probability of selecting public transit for the journey to work is greater in areas near the CBD and areas with higher densities. These findings are significant since the automobile is primarily used for work travel, and occupancy levels are lowest during the work trip (Metro Toronto Planning Department, Metro Cordon Count Program, 1977).

The degree of congestion and average speed of vehicles in the transportation network also affects energy consumption. Automobiles, which consume 65 per cent of transportation energy, are most efficient at speeds of 48 to 72 km/h. Where speeds are substantially below 48 km/h, as in congested inner city traffic, efficiency is reduced and fuel consumption increased. This is attributable not only to the lower speeds, but also to the greater number of idle, stop and start cycles in congested CBD traffic. Cities with several centres of activity (polynucleated) have less traffic congestion than traditional concentric cities, and are therefore, more energy efficient.

Three alternative scenarios can be identified which reduce overall energy consumption in the transportation sector. The first would alter urban form, through changes in density and land use mix, to make alternative transportation modes attractive. The altered urban form would be compact, with multiple centres of activity. Carefully managed redevelopment, rehabilitation, conversion, and infill in existing areas and development controls in new areas would minimize sprawl, strip development, and underutilized land. Multi-unit, low-rise densities in most areas would be sufficiently high to make public transit viable. Places of work, shopping, and recreation would be well related to residential uses, transportation networks, and each other. Mixed use centres would be clustered along transit corridors, and larger complexes in the multiple urban centres would incorporate a wide range of activities to mutual advantage.

The second scenario, assuming the greatest difficulty lies in getting people out of their cars, would require the provision of convenient alternative modes of transportation and the elimination of measures which favour or encourage automobile use. Once the automobile was relegated to a subsidiary role, urban form would develop along conserver lines. The third scenario assumes a reduction in personal automobile use is unlikely, despite increasing fuel costs and disincentives, so that effort would be directed towards finding alternative fuel sources and making cars more energy-efficient. Changing urban form to reduce average travel distances would help make car travel more energy efficient. Attempts are being made to implement all of these scenarios to various degrees.

ENERGY CONSERVATION MEASURES AT THE CITY SCALE

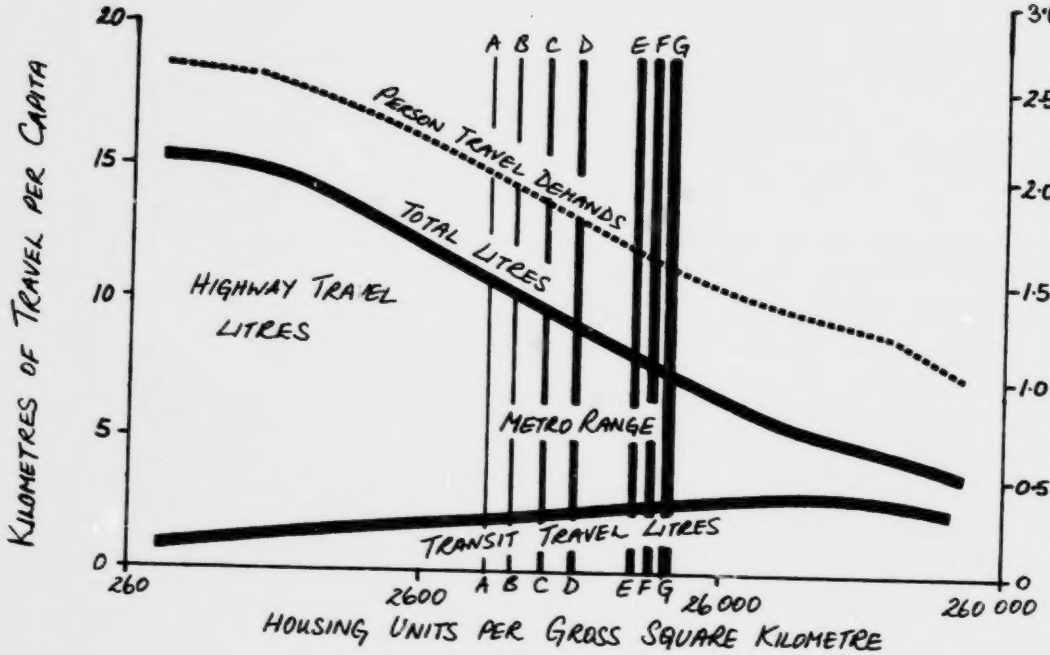
Urban form can be altered to facilitate the change to more energy efficient transportation modes, to reduce trip time and length, and to reduce the general propensity to travel. Those ends can be achieved by increasing urban densities to levels that would make more energy-efficient transportation modes viable, such as public transit, van-pooling, bicycling, and walking; and by mixing land uses to reduce trip time and length for work, shopping, and recreation.

Generally, the costs and benefits of alterations in urban form vary as a function of the current size and form of the urban area, as well as climatic, economic, cultural, and historical factors.

Residential Density

Increased residential density means more people per given area, and generally results in lower transportation and residential energy consumption. The main advantage of higher density is the possibility of reducing the average trip length by decreasing the distance between certain origins and destinations. In the Metropolitan Toronto Area Transporation and Energy Study, Wilbur Smith and Associates (1980) found that as housing density increased ten-fold from 3.9 to 39.0 du/ha, weekday vehicle travel, measured in kilometres of travel per capita, decreased by 40 per cent (Figure 10).

Figure 10. Development densities versus travel and fuel consumption (adapted from Wilbur Smith and Associates, 1980).



DENSITIES

A-SCARBOROUGH	4357
B-ETOBICOKE	5241
C-NORTH YORK	6799
D-EAST YORK	7793
E-YORK	14 947
G-CITY OF TORONTO	16 538

When a city grows in population and physical size, average trip distance lengthens. The World Bank (1976) has postulated that, for a given population density, trip distance increases roughly in proportion to the square root of the radius of the city. For example, if a city grows in population from one to two, four, and then eight million people, with a constant density, average trip distance may be expected to increase from its initial level by roughly 20, 40, and 65 per cent respectively.

Sewell and Foster (1979) compared two model cities with the same two million population, one with a density of approximately 22 du/ha and the other with 11 du/ha, and found that the average trip distance in the latter is likely to be 20 per cent longer.

Increased residential density is also associated with increased transit ridership. This reduces the number of vehicle kilometres and the corresponding energy necessary to provide a given level of transportation service (i.e., passenger kilometres).

Harwood (1977) presented the theoretical example of Sioux Falls, South Dakota where, by increasing densities to levels suitable for efficient public transportation, the city could save 90 per cent of the transportation energy required to service more dispersed development. A fairly large population must accompany increased density in order to justify initial and continuing expenses. Gilbert and Jariss (1973) suggested that energy consumption in the transportation sector is highest on a per capita basis in cities between 5000 and 25 000 persons and steadily decreases in larger cities, mainly due to increased density and the provision of public transit.

An American Congressional Report (Committee on Banking, Finance and Urban Affairs, 1980) found that 60 per cent of the users of Bay Area Rapid Transit (BART) in the San Francisco area still drive their cars to the train, and 90 per cent of Lindenwald Line commuters in New Jersey go part way by car. Although still a net energy saver, public transit loses many energy-saving characteristics when serving widely scattered populations.

Increased residential density also achieves higher per capita use of existing road, sewer, water, electrical, and other utility networks, thus reducing the initial and continuing costs of expanding these. Higher densities can also increase space-heating efficiency and make the use of district heating cost-effective. As much as 40 per cent of space-heating demand can be saved by encouraging medium-density development as opposed to single-family residences, according to Griggs (1978). This is due to the greater energy efficiency of higher-density building forms.

The terms "higher" or "increased density" need to be defined to clarify this discussion. They are used here to refer to an overall medium density. Densities which are too high or low result in the use of more energy both for construction and for operations and maintenance. Apartment blocks require extra energy for elevators, as well as for heating or cooling and lighting common areas. What is most energy efficient, is an overall optimum density, achieved by narrowing the range of density within the urban area so that extreme lows in the outer suburbs and extreme highs at the city core are eliminated.

John Hix (Miloff, 1980) proposed a guideline for a residential density of 67 du/ha implemented through the use of four-storey stacked townhouse structures with self-contained dwellings of two storeys each. Increases above this recommended density, Hix stressed, would result in the use of apartment structures that require more energy per dwelling unit, not only to construct, but also to operate.

Mixed Land Use

Increasing residential density is of prime importance if energy consumption is to be reduced at the city level. Further savings in energy accrue if journeys to work and other travel are reduced by mixing land uses to bring employment, commercial, civic, and recreational uses closer to residential areas.

Attempts have been made to find the optimal land-use arrangement (Edwards and Schofer, 1975; Schofer and Peskin, 1977), but most have concentrated on the relative location of residential and employment areas. Clustering of these uses has been proposed as a means of reducing energy consumption for the work trip (Fels, 1975), whereas in Davis, California, work in the home is encouraged to reduce the propensity to travel.

In planned communities, particularly where residential and employment-related land uses are compatible, significant reductions have been identified in average length of trips. Schneide and Beck (1973) for example, indicated that the relocation of only 25 per cent of the population plus 45 per cent of employment would result in a decrease of 40 per cent in travel time plus a 60 per cent decrease in congestion on the busiest road. Although the energy savings of these changes were not analysed, they would appear to be significant.

The mixing of commercial uses with higher-density residential areas conserves transportation energy. In Portland, Oregon, it is estimated that a potential reduction of 1.4 per cent in the total energy used for transportation could be achieved by establishing neighbourhood grocery stores at 0.8 km intervals.

Careful location of schools and decentralization of social and community services would likewise reduce the usage of transportation energy. The close proximities of different land uses would encourage people to walk. Even if this were only a partial substitute for other modes of travel, consumption of transportation energy would decrease on a per capita basis.

The location of residential, employment, and commercial land uses affects the role and efficiency of public transit. Higher occupancy levels improve the efficient use of transit energy, but extremely high or extremely low occupancy levels along portions of a transit route should be avoided. Stringing residential, employment, and commercial uses along transit corridors can realize savings in energy. Whereas the linear city may be the best form for conserving energy, and ideal for transit, the ideal automobile city may be polynucleated, but a radial city combines elements of both forms (Figure 11). The optimum city form and mix of land use depends on the goals of policy makers.

Other Measures

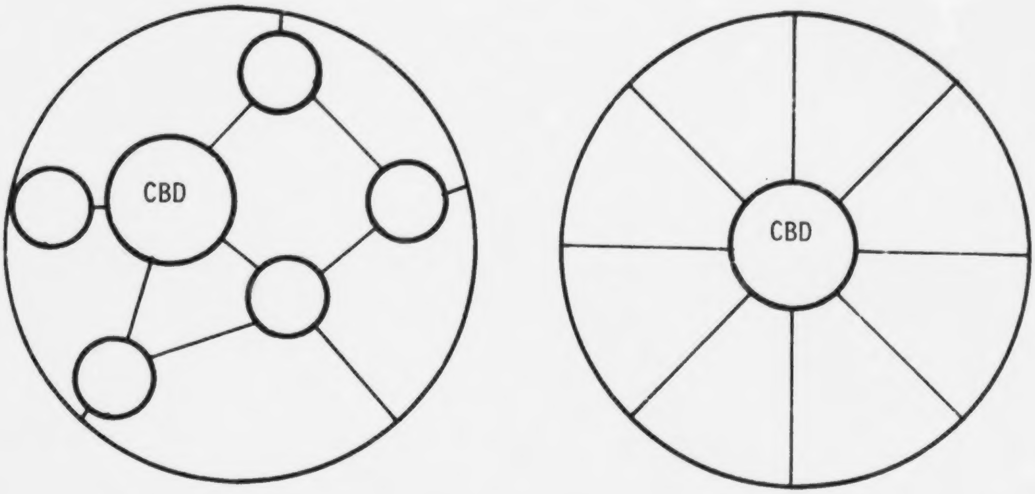
Other conservation measures related to city-level energy consumption include mapping general constraints and the modification of urban systems.

The mapping of general constraints is a technique that determines the most suitable areas for new development in a city. It involves analysis of existing constraints to development, including geotechnical, topographic, climatic, biotic, and cultural constraints, to determine which areas are suitable and which are unsuitable for different forms of development. This saves energy capital in development, reduces energy consumption in subsequent maintenance operations, and helps to prevent development in hazardous areas.

In Thunder Bay, Ontario, general constraints mapping was used to compare alternative patterns of urban growth in terms of servicing costs, to ensure that development would proceed according to the least-expensive alternative. The potential savings should be in the same order as the millions of dollars saved by communities in Massachussetts through using soil survey information to select school sites, to control subdivision development, to protect community water supplies, and to advise developers on sewage disposal systems. Several of these U.S. communities indicated savings in the order of 110 to 1 effected by avoiding errors in the use of land, which represents large savings in embodied energy or energy capital.

Modifying urban systems can save energy in development and in city operations. Urban systems include roads, utilities, public

Figure 11. City form and energy efficiency.

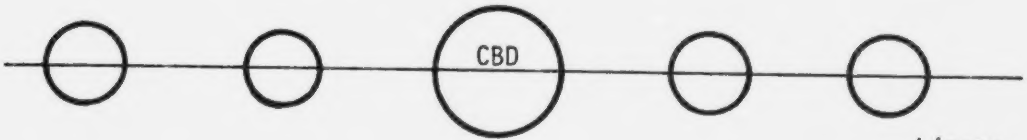


Polynucleated

- efficient mixed use form

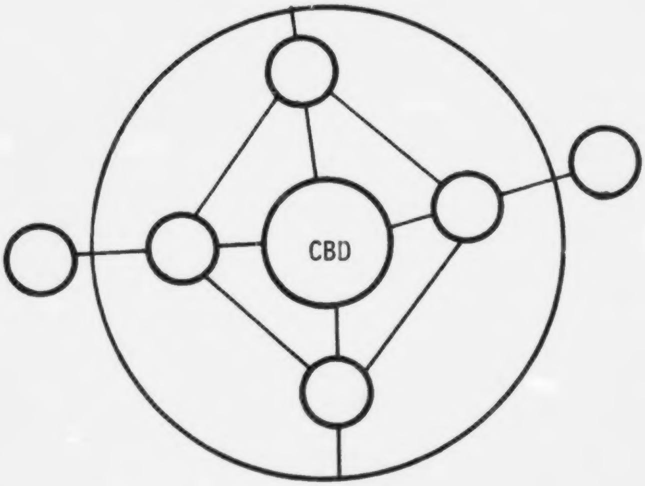
Concentric

- inefficient form



Linear

- efficient transit form



Radial

- combines efficiencies of polynucleated and linear forms transit, garbage disposal, and other municipal operations including street lighting.

In Mississauga, Ontario, a program was initiated in 1978 to convert all street lighting in that city to a high-pressure sodium system. The total conversion cost of approximately $160 000 will be amortized in eight years. A reduction in electrical consumption of 700 000 kW.h annually, due to the more-efficient lighting, saves an estimated $40 000 per year.

IMPLEMENTATION STRATEGIES

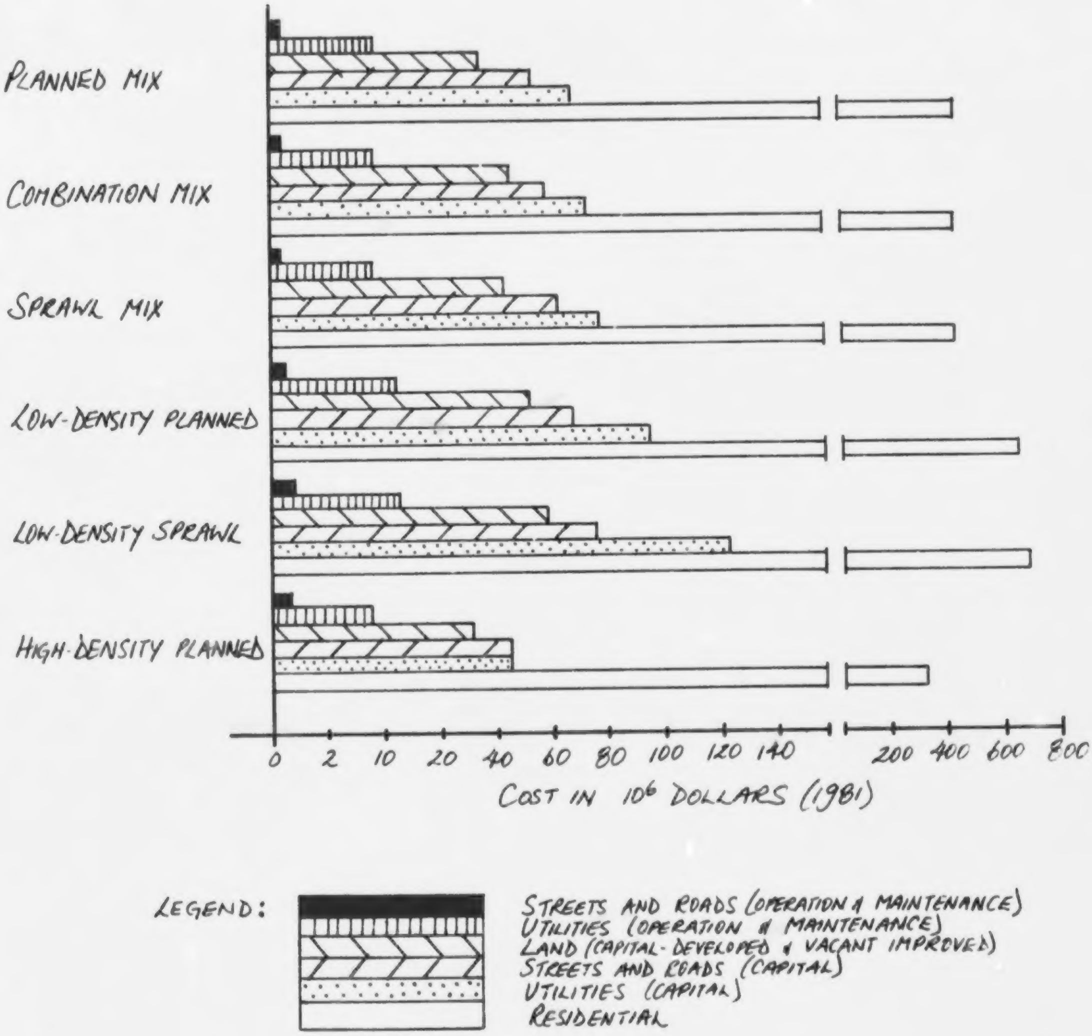
New Development

Increasing residential density and mixing land uses can reduce the energy requirement for transportation by between 5 and 40 per cent. The application of such approaches to areas of future expansion requires careful planning by both the public and private sectors.

The vagaries of urban land holdings often lead to new development not being contiguous with existing built-up areas. Such leap-frogging creates large gaps of undeveloped land in the urban area and, like low-density sprawl, contributes to high energy consumption. Leap-frogging results in increased travel distances, makes alternative forms of transportation expensive, and necessitates lengthy and costly extensions of existing road and utility networks. In addition, much prime cropland near metropolitan areas is lost through inefficient development.

The "Community Direct Cost Analysis" Chart (Figure 12) illustrates the costs that could be incurred by a community as a result of different types of new development. For purposes of clarification, "low-density sprawl" and "high-density planned" are at opposite ends of the efficiency spectrum. Of particular significance to energy consumption and potential conservation opportunities are the capital costs indicated for utilities and road construction associated with low-density sprawl. A community could save as much as 32 and 40 per cent on the provision of utilities and roads, respectively, if development were high-density planned as opposed to low-density sprawl. Higher-density planned communities use 44 per cent less energy than unplanned, sprawling communities (Real Estate Research Corporation, 1974). Other research suggests this figure should be closer to 14 per cent. A range from 15 to 20 per cent would be credible on the basis of recent research.

Figure 12. Community direct-cost analysis for 10 000 units.
(Real Estate Research Corporation, 1974)



	% SINGLE-FAMILY (CONVENTIONAL)	% SINGLE-FAMILY (CLUSTERED)	% TOWNHOUSE (CLUSTERED)	% WALK-UP APARTMENTS	% HIGH-RISE APARTMENTS
PLANNED MIX	20	20	20	20	20
COMBINATION MIX (50% PVD, 50% SPRAWL)	20	20	20	20	20
SPRAWL MIX	20	20	20	20	20
LOW-DENSITY PLANNED	25	75			
LOW-DENSITY SPRAWL	75	25			
HIGH-DENSITY PLANNED		10	20	30	40

Existing Development

Although measures for energy conservation are more easily applied to areas of new development, approximately 70 per cent of the urban infrastructure required by the year 2000 in Canada already exists. Existing development, by its very size, has the greatest potential for energy savings, yet, at the same time, it is more difficult to alter. Restructuring existing parts of the urban area may entail higher capital costs and energy use than developing new areas and may require institutional changes in planning, and in architectural and engineering practices. Since road and utility networks are already in place, however, the millions of dollars associated with providing them in new development can be eliminated. Similarly, operating and maintenance costs and energy can be substantially reduced. However, the economic benefits can be partially offset by high land prices.

Altering existing developed areas implies redevelopment, rehabilitation, and conversion or infill development, or any combination of these strategies depending on the structure and quality of each area.

Redevelopment

Redevelopment of existing areas facilitates replacement of older, less energy-efficient environments with energy-conserving forms, and typically occurs in older core areas where it is not economically feasible to upgrade the existing properties.

The Winnipeg Core Area Initiative demonstrates the type of incentives required, in most instances, to upgrade decaying core areas. The program, funded by three levels of government, identifies and implements projects that will improve the social, economic, and physical components of the city core, making it both attractive and functional.

The decision to redevelop an older area is not likely to be made on the basis of energy conservation alone but, although redevelopment is normally associated with high initial costs, long-term energy costs can be reduced. During redevelopment, the potential exists to implement planned unit developments (PUDs) or mixed-use complexes. PUDs can have medium or high residential densities and sometimes mixed land uses. Mixed-use complexes often combine a wide range of business, commercial, entertainment, and residential land uses, resulting in predominantly self-contained areas where travel distance may be markedly reduced.

Providing one kilometre of roads, water, and sewer lines in a new low-density suburb of single-family homes costs about $312 000 (1980), assuming a density of 7.9 du/ha. In a typical city, due to obstructions and higher land costs, the same kilometre of new facilities laid in a developed area, would cost about $406 250 (23 per cent more). Obviously, savings are not related to the original construction, nor are they related to operations and maintenance costs, which are about the same. Savings arise because of population density, such that the per capita cost of providing the facilities in the low-density suburb is $5 000, but in the city, it is only $540 (89 per cent less).

Planned unit developments and mixed-use complexes already exist in many Canadian cities. Although not built with energy conservation in mind, these developments have produced energy savings related to transportation by reducing distances travelled between home and services. Calgary's Eau Claire represents a downtown redevelopment that is characteristic of PUDs and incorporates higher-density apartments and row housing within a mix of land uses. Similarly, the Bay Complex in Toronto attempts to rejuvenate the downtown core by providing a mix of residential, commercial, and office facilities within a megastructure that occupies an entire city block. In both examples, public transit facilities are integral parts of the developments.

False Creek and Granville Island are examples of urban eyesores turned into attractive environments close to the heart of a city. False Creek is a medium-density residential redevelopment in Vancouver located close to work, shopping, and recreational opportunities in the converted and revived industrial area on Granville Island.

Rehabilitation and Conversion

Rehabilitation of older neighbourhoods provides an opportunity to revitalize areas without changing their character whereas conversions can change densities and land uses. There are many examples of rehabilitation and conversion in Canadian cities which, although initiated for reasons other than saving energy, do incorporate attributes that have a potential to conserve energy.

Toronto's Cabbage Town has progressed rapidly from an area of run-down tenements to a highly desirable neighbourhood with easy access to the city core. What started as cautious rehabilitation of 19th century row-housing purchased at low prices, has escalated to the point where living in one of these renovated units has become fashionable and expensive.

Conversion in existing neighbourhoods can increase density and provide for a mix of land uses. Large older homes in many Canadian centres have been upgraded and converted to multi-family dwellings. Others have been converted to incorporate multiple uses, such as commercial on the first floor level and residential on the upper floors. Sometimes inner city initiatives are fortuitous; sometimes they are planned. Toronto experienced a wave of rehabilitation and conversion after passing a by-law restricting building heights in the downtown area. The Yorkville area of Toronto is a prime example of a rejuvenated older residential area that incorporates mixed land use. Rehabilitation and conversion often provide the stimulus for infill developments.

Infill

Infill development creates an opportunity for significant energy savings within existing developed areas. Most cities have large areas of vacant or underused lands. Winnipeg is estimated to have enough undeveloped land suitable for infill to accommodate the growth of the city for the next twenty years (Peter Barnard Associates, 1980). If this land is properly developed, more efficient use can be made of the existing infrastructure.

Within most Canadian cities there are obvious benefits to infilling vacant or underused lands, particularly from the stand-point of reducing transportation energy consumption associated with new residential development in outer suburban areas. Barnard found annual personal transportation costs within the city were approximately 51 per cent less expensive, and therefore less energy-consuming, for families living downtown as opposed to the suburbs. A four-person family in the city, with one car, incurred annual transportation costs of $2460 (1981 prices), whereas a similar family in the suburbs, with two cars, incurred annual costs of $5120.

The viability of infill development is dependent on a complex set of circumstances that differs from location to location. This includes market demand, economic viability, municipal policy, and the support of concerned parties.

Infill is primarily small-scale; it can help maintain and reinforce existing healthy neighbourhoods and can be a catalyst for some neighbourhood revitalization. Infill alone, however, is not of sufficient scale to have a major impact in large areas of decline. Nevertheless, it can be part of a major revitalization effort, involving improvement of public services and facilities, rehabilitation of existing housing, and the development of new infill housing.

Planning Strategies

A number of urban centres in North America have introduced legislation to stimulate the development of energy-conserving urban forms in various ways. Restructuring existing urban areas to increase density and mixed land uses requires special policy and design strategies, often changing accepted standards. Legislation to encourage such restructuring must be flexible, as well as readily acceptable and easily implemented.

Energy management programs and the introduction of conservation measures in development plans, secondary plans, zoning by-laws, and development agreements may save energy in several ways. First, changing conventional housing type and density requirements to broad general categories will permit energy-conserving house forms and innovative development and redevelopment. Secondly, encouraging and allowing different land-use mixes improves residential proximity to commercial, social, and recreational facilities and makes more efficient use of public transportation. Thirdly, using environmental constraints mapping as a general guide to development ensures that land uses are suited to the area and that they cause the least environmental hazard. Lastly, modifying urban systems increases energy efficiency.

The following examples illustrate how certain jurisdictions have implemented comprehensive policies for energy management and conservation.

San Diego, California

The San Diego County General plan is composed of several 'elements', of which the "Energy Element" is a major policy statement regarding the County's role in planning for energy resources (County of San Diego, Integrated Planning Office, 1977).

The major topics in the "Energy Element" of the plan are presented as scenarios that address energy demand and supply, the effects of various conservation tactics, the rationale for selecting a reduced rate of energy growth, and the policies and implementation strategies required to reduce the rates of energy growth to desirable levels. Emphasis is placed on implementing strategies that have been found to have substantial savings, either independently or in combination with others.

Of particular significance are policies which attempt to reduce the energy consumption associated with transportation, general land uses, and housing through the restriction or modification of undesirable development. Increased development densities are encouraged through emphasis on attached residential units in new areas and infilling in existing areas. Land uses aimed at minimizing transportation are promoted, such as a greater mix of residential and commercial or equally compatible land uses. Other policies promote mass transit, bus service, and walking and bicycle routes within the County. The plan recognizes that the transportation sector is a major user of energy and that choices between developed modes of transportation will be the prime determinants of future energy needs. Attempts have thus been made to promote interconnections between planning decisions related to land use and those related to transportation. Attempts have also been made to incorporate performance parameters for the year 2000, to demonstrate each policy's effectiveness relative to the others.

Portland, Oregon

The City of Portland (population 365 000) has taken a legal and regulatory approach to conservation by developing a comprehensive energy plan that relies heavily on the city's power to shape growth and mandate conservation. After 1984, homeowners will have to meet mandatory weatherproofing requirements such as installing storm windows and insulation. Loans for this are available through a HUD Action Grant matched by local lenders. Cost-effective standards require that the cost of weatherproofing and new fuel bills be less than, or equal to, previous fuel bills. Rental and business properties face similar stiff requirements. The plan also has a land-use component encouraging compact growth and integration of new development with mass-transit systems.

Portland was one of the first cities to attempt to quantify potential energy savings related to the application of particular land-use strategies (Table 3). The main objective of the Portland Energy Conservation Management Demonstration Project was to develop a methodology that could be used to predict potential energy savings from changes in the urban form. The savings realized from 85 conservation programs were calculated and the 42 with the greatest potential were used in assembling a comprehensive energy plan.

The methodology used to calculate energy savings was designed to be applicable to other U.S. cities, although the savings would differ with climate and building code. It has potential for application in Canada.

Portland is also considering use of energy zones. Priority would be given to capital improvements and development proposals in zones well served by public transit, utilities, and services near the CBD and close to employment and shopping.

Table 3. Transportation and land-use conservation choices, City of Portland, Oregon

Implementation program	Maximum 1995 energy savings billions (10^9) kJ per year	Maximum savings of regional 1995 projected demand	
		Transportation	Residential
RESIDENTIAL LAND USE AND TRANSPORTATION		%	%
Townhouses and apartments along transit street	11 621.5	6.0	7.6
Townhouses and apartments near employment centres	8 840.3	5.4	5.7
Townhouses and apartments near shopping centres	9 935.5	5.3	6.7
Townhouses and apartments near transit stations	9 937.6	6.2	6.2
Zoning change to allow apartments in large homes	1 040.3	1.2	1.3
Infill housing on vacant single parcels	270.1	0.2	---
Require two-storey construction in dwellings greater than 102 m^2 (handicapped persons excepted)	929.5	---	0.4
COMMERCIAL/INDUSTRIAL LAND USE AND TRANSPORTATION			
Neighbourhood grocery stores	1 269.2	1.4	---
Limited expansion of strip retail development	174.1	0.2	---
Allow home occupations (office type)	153.0	0.1	---
Re-use of waste heat	1 831.6	---	2.5
PUBLIC LAND USE AND TRANSPORTATION			
Build exclusive bicycle paths	287.0	0.3	---
Lower speed limits to 70 km/hr	366.1	0.4	---
Improve traffic flow	418.8	0.4	---
Car/van pool incentives	3 589.1	6.1	---

Adapted from: Policy Analysis Section, Bureau of Planning, City of Portland, Oregon (1977).

Seattle, Washington

In 1976, the City of Seattle (population 500 000) passed five resolutions that together comprise a comprehensive municipal energy policy. The resolutions involve the following:

(i) developing new building codes for energy efficiency aimed at improving construction in terms of thermal performance and increasing residential densities;

(ii) forecasting electrical demand to project baseline levels of electrical energy demands;

(iii) specifying energy conservation policies in the city's comprehensive policy plan;

(iv) managing power generation with due consideration to resource use, energy conservation, sound economics, and environmental responsibility; and

(v) preparing a contingency planning program for energy use.

The plan seeks to use land in downtown Seattle more efficiently: intermixing living and working space in a denser pattern, and thus reducing energy otherwise consumed in commuting. Free bus service for the downtown is intended to cut down on the use of automobiles. Residents seeking to switch to electric heating must install insulation and other energy-saving features. The city is also investigating other energy sources including coal-fired generating plants, and biomass, solar, and wind energy.

Toronto, Ontario

As a result of concern over rising energy costs, Toronto City Council passed a by-law to amend the Official Plan and include statements on energy efficiency. Toronto, a city of 610 000, within a census metropolitan area of nearly three million, is a fully developed inner city with a vital core area, a mixture of high-density residential complexes and mature, low-density residential neighbourhoods, and a multi-modal transit system.

The goals of the by-law are to minimize energy use while improving the quality of urban life, to replace the consumption of non-renewable resources, particularly oil, with renewable energy sources, and to minimize inequities for residents caused by higher energy prices and possible shortages. Policies pertain to energy conservation, urban form, and public involvement, and are guided by the principle that all measures should be cost-effective.

The City has completed a Municipal Energy Audit and is exploring such measures as the cogeneration of electricity and steam for district heating and the use of sewage for district heating, and is developing guidelines for assuring solar access in medium- and high-density developments. Also, a demonstration program in community retrofit has been started.

Winnipeg, Manitoba

Awareness of the benefits of energy saving in restructuring Winnipeg toward a more compact and integrated form is growing. Plan Winnipeg 1981, although nowhere specifically mentioning energy, consistently emphasizes policies to strengthen Winnipeg's developed areas through infilling, and limiting development beyond the existing built-up area. The plan sets the tone of political and administrative action in the city (population 600 000). Developers proposing expansion subdivisions are being required to provide full assessment of the capital effects of their developments.

In Canada, slow-growing cities such as Winnipeg, and cities with major geographic constraints to expansion like Vancouver, have begun to focus inward. Even fast-growing urban centres without major impediments to expansion, such as Calgary, have instituted policies to increase urban densities and stimulate infill. In urban regions such as Toronto, certain policies, as well as the economics of size, have been shown to have the effect of stimulating migration to, and redevelopment of, the downtown.

Davis, California

The City of Davis (population 36 000) is attempting to reduce energy consumption with respect to work-related travel, by encouraging people to live and work in the same neighbourhood. A number of different ordinances have been passed to implement this objective including the encouragment of cottage industry by allowing home owners to operate small businesses.

The Davis General Plan encourages a wide variety of measures for energy conservation, including shading, drought-resistant vegetation, alternative transportation modes (bicycles and transit), recycling non-renewable material, conservation of prime agricultural land, and energy-conservation standards for buildings. The City enforces these planning policies through ordinances and development reviews.

Between 1973 and 1978, electrical consumption in Davis dropped 10.1 per cent and the consumption of natural gas dropped 25.9 per cent, while other centres in the general vicinity experienced increased consumption of electricity and a much slower decline in natural gas consumption. Some declines in energy use were found to have occurred in Davis prior to implementation of the General Plan, however, distorting estimates of energy savings resulting from these policies.

Montgomery County, Maryland

In Montgomery County, on the other hand, planners, developers, and politicians are encouraging mixed land use in their community, and higher residential densities in relation to public-transit routes, through a zoning by-law. By permitting the mixture of some uses and allowing others on special permits, it is maximizing public-transit uses, bicycling, and walking and minimizing reliance on the automobile. Montgomery County has a variety of mixed-use zones. The TS-R zone, for example, is designed to combine several types of residential uses with institutional and local commercial uses. Hotels, restaurants, grocery stores, and drugstores are allowed by special permit. The zone is flexible in the design, layout, and grouping of different uses to facilitate their successful integration in a residential transit zone.

Boulder, Colorado

The City of Boulder (population 80 000) encourages new development close to a variety of existing facilities and services by granting bonus points to developers who must compete for a limited number of development permits annually. The maximum number of points is awarded for the following distance parameters:

- the project is within 1.2 km of a developed neighbourhood park
- half the project is within 0.4 km of existing bus service
- the project is within 1.6 km of three of the following facilities: library, recreational centre, day-care centre, neighbourhood shopping facilities with at least one grocery store
- the project is within four minutes of fire department response, and
- the project is within safe walking distance of two of the three schools that serve it (distance unspecified).

Windsor, Connecticut

The Town of Windsor offers density bonuses to encourage conversions from one- and two-family residential structures to office and multi-family use if the projects are near convenience shopping and mass transit. Other requirements and incentives set forth in zoning regulations include: first, for planned unit developments, that all residential units must be within 2.4 km of one elementary school and within 1.6 km walking distance of an existing bus route; and secondly, for developments in the CBD, that if the location of the development generates sufficient pedestrian, bicycle ,and mass-transit trips, required parking may be reduced up to 10 per cent, subject to the discretion of the Planning Commission.

Windsor has also reduced subdivision standards for the width of culs-de-sac and one-way-loop local streets. When parking is restricted to one side of the street, culs-de-sac may be 7.3 m wide and one-way-loop local streets 6.1 m wide. The previous standard for both was 9.1 m wide.

Brampton, Ontario

Brampton (population 140 000) was the first city in Canada to require the application of the principles of passive solar design to all new subdivision plans. The Brampton bylaw is based on eight energy conservation criteria, including siting and designing buildings for solar orientation and solar access, designing for pedestrian access and use of public transit, and developing mixed-use centres. The criteria also formed the basis of the City's energy policy concerned with:

- promoting greater local self-reliance
- reducing consumption of non-renewable energy sources
- siting buildings for proper sun and wind orientation
- protecting solar access
- encouraging mixed-use developments and a comprehensive waste recycling program, and
- promoting public transit.

In 1979, the Brampton City Council approved the formation of an Energy Conservation Committee to analyze energy use by city-owned or operated facilities, to prescribe conservation measures, to monitor future energy use by municipal facilities, and to involve the general public in a program of public relations and information dissemination. Public understanding and involvement are deemed essential if passive solar and other design measures being applied to subdivisions are to achieve their potential energy savings.

MUNICIPAL TECHNIQUES

Municipalities can effect large changes in energy consumption through their policy decisions. Many changes in urban form, often the result of economic lobbying, social planning decisions, or other factors, effect energy conservation. In many Canadian cities, economic and lifestyle factors have led to the development of PUDs and higher-density zero-lot-line housing forms, that increase density and save energy. Social factors have stimulated inner-city revitalization through conversion of older houses and obsolete land uses, mixing land uses, and infilling. In the long run, such actions save energy in urban transportation and in the development of new infrastructure.

The examples cited indicate several techniques for achieving energy conservation:

(i) energy management programs and teams help to keep energy expenditures low;
(ii) development plans and policy statements provide a general framework for conservation actions;
(iii) bylaws, codes, and other development controls regulate conservation actions; and
(iv) the process of development approval encourages the understanding and application of energy conservation techniques in new developments.

Energy management teams provide expertise to advise municipalities on energy problems, conservation strategies, and implementation techniques. They also manage and monitor conservation actions.

Municipal development plans influence community goals, the kind of development allowed in different areas, and the timing and capacity of municipal infrastructure. They have a significant effect on overall urban form. A statement on energy policy may be developed as part of a development plan, or as a separate document. Energy policies include either direct actions dealing with problems over which a municipality has total or substantial control, or advocate actions dealing with problems over which a municipality has little or no control.

Bylaws, building codes, and other development controls are specific regulations that provide the means for implementing strategies in energy conservation. Coupled with a process for development approval that encourages the understanding and application of energy conservation techniques, such regulations will ensure that energy-saving measures are built into new urban environments. The approval process may serve, as well, as a means of educating developers in energy conservation and encouraging innovative energy-saving plans.

The extent to which any of these implementation techniques fit a particular city depends on the local energy situation, public awareness of energy issues, the concern of local government, and unique factors of geography, history, and government. The energy crunch in the Pacific Northwest of the United States focused public awareness and local government concern, and led to the formulation of tough, comprehensive energy policies and development controls. Similarly, energy legislation in San Diego County and Davis, California, was the result of the threat of real energy shortages. In areas that are secure in short-term energy supplies, the move toward energy conservation is more the result of economic arguments. Winnipeg and Calgary would like to limit peripheral development and encourage infilling to minimize future capital costs.

CHAPTER 3

NEIGHBOURHOOD - LEVEL APPROACHES

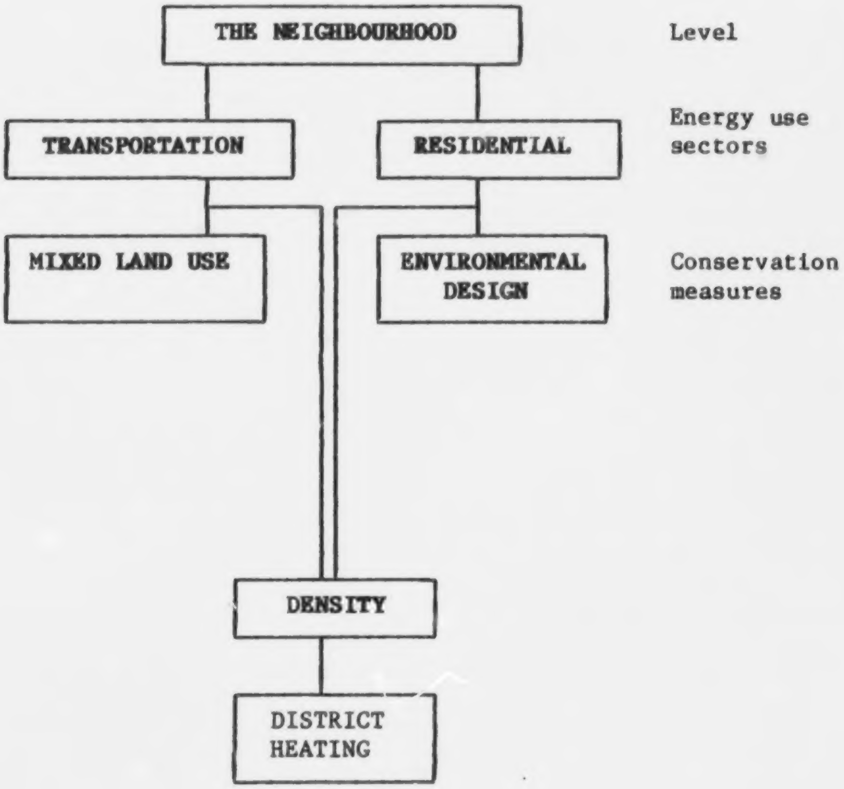
Neighbourhood energy conservation focusses on four main approaches -- compact form and mixed land use, district heating, environmental design, and solar access.

These approaches are made up of sets of design principles (Figure 13). Energy conservation at the neighbourhood level requires trade-offs between those principles which are not compatible. In order to demonstrate the energy-saving potential of the different approaches, as well as to indicate where trade-offs must be made, this chapter is organized in terms of general costs and benefits, energy conservation principles, examples, and conclusions.

Both embodied and operational energy can be saved through the application in the neighbourhood of energy conservation principles. Embodied energy is the amount of energy expended to manufacture and put building and infrastructure materials (and systems) in place. Operational energy is the amount of energy expended in the day-to-day functioning of a neighbourhood, including space conditioning (heating or cooling buildings), heating water, running appliances, operating vehicles, and maintaining infrastructure. Compact form, mixed land use, and environmental design approaches save both embodied and operational energy, whereas the district heating and solar access approaches save only operational energy. District heating and solar access are space-heating approaches the effectiveness of which must be measured against the viability of other systems for energy transmission and exchange. The effectiveness of district heating is related to compact form and mixed land use, and that of solar access to environmental design. Compact form, mixed land use, and environmental design principles have a more general applicability and a greater potential for overall energy savings than district heating and solar access per se. The magnitude of the potential energy savings for any approach or combination of approaches varies between individual development sites, as well as between energy zones.

An important consideration in determining energy savings related to a particular energy-saving approach is the thermal efficiency of housing units. As the thermal efficiency of the building envelope improves, the marginal energy contribution of energy-conservation measures such as district heating, wind protection, and solar access, becomes less important, and they are no longer cost-effective options. Careful consideration of the costs and benefits of low-energy residential design should be a first step

Figure 13. Opportunities for energy conservation at the neighbourhood level.


THE NEIGHBOURHOOD
Level
TRANSPORTATION
RESIDENTIAL
Energy use sectors
MIXED LAND USE
ENVIRONMENTAL DESIGN
Conservation measures
DENSITY
DISTRICT HEATING

in neighbourhood design for energy conservation.

Ultimately, the decision to apply certain conservation measures may be based on concerns other than the economics of energy. Marketability, development regulations, and technical know-how may severely limit the application of energy conservation in a development.

The concerns in initiating energy conservation at the neighbourhood level are several.

Marketability

Consumers' reluctance to accepting innovative conservation measures and builders' resistance to including such options, is a major concern in incorporating conservation approaches. Uncertainty about exact energy savings, coupled with the lack of performance guarantees, are the two largest obstacles to selling energy-efficient plans.

Cost-Benefit Accrual

Developers of new, energy-conserving housing are concerned about the disparity between who pays for, and who benefits from, energy-efficient buildings. Whereas the risks are often taken by the developer and builder, the benefits generally accrue to the consumer, public utility, or public at large.

Development Regulations

Local development restrictions can present unintentional barriers to energy conservation. Even conservation-oriented bylaws can hinder the application of worth-while principles. Solar access bylaws which require all streets to be oriented east-west, for instance, may ignore the energy-conserving benefits of designing with existing topography, while solar access can be ensured through performance standards for window orientation.

Technical Know-How

Although a general list of planning principles for energy conservation at the neighbourhood level is emerging, a specialized team is often required to identify, screen, and evaluate the means of increasing energy efficiency at this level.

Governments will have to ameliorate the current situation if they believe energy conservation to be worth-while, especially if energy savings have a net dollar cost to consumers. This can be done through demonstration projects, fiscal policy, and revised planning regulations. Neighbourhood conservation measures are essential to savings at other levels. For example, as the size and density of a neighbourhood increases, so does the viability of a public transit system, which is a city-level concern. Similarly, the layout of neighbourhood streets and lots also affects the ability of housing to use solar energy or to channel winds, which is a residence-level concern.

The purpose of this chapter is to outline methods of energy-conserving design. At the end of the chapter is a comprehensive checklist which can be used to review the energy-conserving potential in a given residential development proposal.

COMPACT FORM AND MIXED LAND USE

Compact form and mixed land use save both embodied and operational energy in neighbourhoods. Energy is saved in three main ways: first, by reducing the space conditioning (heating and cooling) requirements of residential buildings; secondly, by reducing transportation requirements within the development; and thirdly, reducing the infrastructure (roads and utilities) required in the development.

The magnitude of savings varies from project-to-project. A rough estimate, based on the findings of a number of studies, suggests that compact form and mixed land use compared to low-density suburban development can save from 10 to 40 per cent of space conditioning requirements, from 5 to 15 per cent of transportation requirements, and from 10 to 20 per cent of infrastructure requirements. Reducing road and utility requirements also reduces operating and maintenance energy use.

Principles

Energy-conserving neighbourhood form involves three parameters: density, mixed land use, and the urban system.

Increasing the density (compactness) of a development from single-family detached housing at about 12 du/ha to multiple housing at 67 du/ha, reduces heating requirements by 40 per cent due to a reduction in exposed surface walls. (The higher density is equivalent to stacked townhousing.) A 33 per cent cost saving (including a saving in embodied energy) can be achieved through developing neighbourhoods with a 20 per cent mix of multiple-family housing rather than homogeneous single-family detached housing (Real Estate Research Corporation, 1974). Greater compactness also increases the viability of district-heating systems and public transit.

Low-density development has inefficient layouts of streets and lots which creates a dependence on the automobile for transportation. The clustering of single-family detached lots, using zero-lot-line regulations and developing higher-density planned units improves transportation and utility energy use while maintaining many of the other attributes of low-density developments.

Planned unit developments (PUDs) are higher-density neighbourhoods with integrated designs for streets, utilities, buildings, and landscaping. Depending on the scale of development, a PUD can incorporate a wide mix of land uses and, depending on local legislation, can modify density, road width, and other, often rigid, zoning and development regulations. A PUD may save as much as 45 per cent of the energy used in sprawl. Neighbourhood PUDs often incorporate cluster development and high-density housing forms.

The second principle concerning neighbourhood form involves mixed land use. This, in conjunction with more compact form, reduces transportation requirements (see Chapter 2). Mixed land use can be achieved through developing multi-use structures, zoning to permit a flexible distribution of land uses, including residential, commercial, institutional, and recreational uses, and encouraging work at home.

The third parameter is improving the efficiency of neighbourhood infrastructure. This includes roads and utilities such as storm and sanitary sewers, water mains, and electrical lines. Planning which reduces the number of local streets and ensures an efficient street hierarchy will also conserve energy (CMHC, 1981). The use of culs-de-sac, although desirable for other reasons, requires extra manoeuvres on the part of snow-clearing equipment, restricts snow storage, and costs more to service than through streets. Reduced distances between housing units reduces the lengths of road and utilities required to service and maintain the neighbourhood. Utility costs, an indication of embodied energy, could be reduced 15 per cent; while operating and maintenance costs could be reduced 5 to 6 per cent between planned high-density and low-density sprawl development (Real Estate Research Corporation, 1974). (Detailed figures indicating neighbourhood savings in embodied and operational energy are found under Environmental Design later in this chapter.)

These three parameters for energy conservation require a thorough evaluation of the overall concept for neighbourhood development, internal zoning, layout of streets, and utilities. Full implementation of the principles of compact form and mixed land use depends on marketing perceptions and development regulations.

The location of a neighbourhood vis-à-vis other urban development is another important consideration in designing for energy conservation. A project remote from existing services and facilities may require excessive energy for the construction of trunk roads and utilities, for transportation and for utility line losses. Where development options are limited, however, developing a self-contained neighbourhood, incorporating all necessary services and facilities, or providing mass transit reduces energy demand.

Reductions in street and utility lengths and creation of a traffic hierarchy with a favourable traffic flow (minimizing stops and starts) reduces inefficient automobile use, and reduces the capital cost of street and utility construction. Street widths can be reduced, in many cases, without impairing this ease of movement, again saving in capital costs, and also reducing heat build-up due to large areas of asphalt. Developing bicycle paths and walkways through a neighbourhood further decreases dependence on motorized transport and saves energy.

Other possible alterations to conserve energy include selecting energy-efficient building systems and materials to avoid energy-intensive construction; wood or masonry walk-up apartments being more efficient than elevator high-rises. Street lighting is another example: reduced street-lighting standards, where consistent with public safety, using high-efficiency low-pressure sodium fixtures, will save in the energy used in the construction and operation of street lights.

Examples

St. Lawrence Neighbourhood, Toronto, Ontario

The St. Lawrence Neighbourhood in Toronto, is a large venture in inner-city redevelopment involving the re-zoning of 18 ha of marginal industrial land to become a residential and commercial mixed use area for a projected 10 000 people. The plan is for townhouses clustered around interior loop roads, buffered from adjacent traffic arteries by specially designed, higher-density apartments containing street-level arcades of shops.

Based on the philosophy "you can't impose a suburban approach on an inner-city development", densities are as high as 135 du/ha. The PUD stretches 1.6 km across 11 city blocks and is cut off from the existing residential fabric of Toronto by a railway line and the Gardiner Expressway.

The development is sensitive to the fabric of the original neighbourhood, with buildings that fit the style and layout of existing city streets, and apartment blocks that are long and low, running the full length of a block. Exterior walls are clad in brick, commonly used in Toronto.

The St. Lawrence Neighbourhood estimates an energy budget of 194 kW.h per square metre per year for the attached housing. This is an 18 per cent improvement in energy use over other projects with a similar mix of apartments and townhouses. Heating systems are hydronic to allow for conversion to a district heating system based either on gas, or steam from a nearby waste incineration plant, or heat pumps in the nearby interceptor trunk sewer.

In addition, the high-density and mixed-use development will save local and regional transportation energy. Proximity to downtown Toronto, along with good public transit facilities provide the opportunity for high levels of transit ridership.

Solar West, Vancouver, British Columbia

Vancouver's Solar West development, a 50-ha tract of City-owned land, employs three of the major approaches to energy conservation at the neighbourhood level, namely, increased densities and mixed land use, environmental design, and solar access.

The net density of Phase 1 of Solar West is 37 du/ha, a level normally associated with townhousing, although most of the residences are semi-detached or joined only by common garages. Smaller, narrower lots allow for intensified land uses.

Recognizing that the transportation system is the largest single user of energy within a neighbourhood, but that many measures for reducing transportation energy consumption require changes in public attitudes, the site plan incorporates measures such as developing pedestrian and bicycle paths, minimizing road lengths and widths, and increasing access to public transit.

The energy use associated with utilities, materials, construction, and maintenance is reduced through smaller service component size, achieved by combining smaller lots and short roads off collector streets on which run the main utility lines.

Burke Center, Virginia

Burke Center employs a number of principles related to compact form and mixed land use. Higher density is achieved through the use of four-plexes and clustering, which reduces requirements for roads and services. Road patterns were adjusted to reduce trip lengths and development standards were modified to minimize street widths and parking requirements. In addition, a park-and-ride system was incorporated to reduce energy use in trips to work and shopping. Burke Center employs an efficient system for solid-waste collection which requires 41 per cent less energy than a conventional system. The principal cost and energy savings for Burke Center relate to infrastructure savings, and these are discussed under Environmental Design later in this chapter.

Davis, California

In Davis new street widths are determined primarily on the basis of the width of fire trucks. The local street right-of-ways were reduced from 10.4 to 8.5 m, with the possibility of further reduction in conjunction with neighbourhood parking bays. The narrower streets require less asphalt, and savings in land and site development could be as high as $1000 per lot.

Davis has also encouraged the use of bicycles and public transit, and developed legislation to encourage work at home.

Conclusions

Compact form and mixed land use as approaches to energy conservation at the neighbourhood level are applicable to all developments. The extent to which the approach can be applied depends on the developer's objectives, market factors, and development regulations. The following principles within this approach have demonstrated energy savings.

1. Densities between 67 and 94 du/ha save between 30 and 40 per cent of the energy used to heat single-family detached housing units.

2. Medium densities and mixed land use produce transportation energy savings in the order of 3 to 14 per cent.

3. Medium densities produce savings in utility costs in the order of 15 per cent and can reduce operational and maintenance costs by 5 to 6 per cent. The equivalent energy savings have not been estimated due to a lack of data.

4. Inefficient energy consumption in off-site transportation, infrastructure construction, and transmission line losses can be reduced by developing continuous built-up areas, or self-contained, mixed-use neighbourhoods, or mass transit.

5. Embodied and operational energy for streets and utilities is reduced on a per unit basis by increasing residential density. This can be done by developing PUDs, cluster housing, or zero-lot-line housing.

6. Embodied and operational energy for streets and utilities may be reduced by efficient planning for these systems. This includes ensuring an efficient street hierarchy, optimizing street widths, and minimizing utility lengths by using special utility corridors.

DISTRICT HEATING

District heating is the centralized generation and distribution of heat in bulk to a number of buildings.

The viability of district heating increases with increased density of demand. District heating is compatible with strategies to increase residential density in existing neighbourhoods and to develop higher densities (67 to 94 du/ha) in future neighbourhoods.

In new neighbourhoods, the viability of district heating will decrease as the thermal efficiency of the housing increases because the requirement for residential heating will decline. District heating will remain an important consideration, however, until all new housing meets conserver-home standards. In existing areas, district heating systems may be more cost-effective than extensive retrofitting to improve the thermal performance of older housing.

The thermal energy for district heating is supplied by a central system fed by one or more plants. The heat transmission fluid, usually steam or hot water, can be used for space heating, absorption cooling, and domestic water heating. Distribution of chilled water is referred to as district cooling. District heating has potential for cogeneration, that is waste heat recovery from electricity production.

The economics of district heating are dependent on the relative capital and operating costs of a centralized heat-supply system as opposed to independent heating systems, considering the following variables:

- number of assured district-heating customers
- capital costs for district heating, including thermal plant, transmission system and, possibly, thermal storage; and the capital cost of independent systems
- availability of various fuels
- cost of borrowing capital
- fuel costs for district heating and independent systems
- projected increases in fuel costs
- viability and economics of cogeneration
- efficiencies of district heating and independent systems

- cost of labour for the district-heating system, and
- cost of maintenance and replacement for the district-heating and independent systems.

District-heating systems can produce heat more efficiently than individual furnaces and can thus save fossil fuel, thereby increasing energy security. Air pollution is significantly reduced in areas where oil is the predominant fuel, and the fire hazard in residences is reduced due to the use of flameless heat. Despite numerous benefits, the high capital costs of district-heating systems suggest that subsidies or inducements will be necessary to encourage their use, since they will initially be less attractive to consumers than those independent systems which offer low capital costs and high levels of efficiency. In existing developments, the willingness of consumers to convert to district heating will depend on the relative prices of heat sources at the time of conversion and the cost to the consumer. All potential consumers must convert to ensure the optimum efficiency of the system.

Examples

European Experience

District heating has been used in Northern Europe for over half a century and has increasing economic and environmental advantages over conventional independent heating systems there. Fossil fuels -- coal, oil, and natural gas -- are their main sources of heat. Due to the increasing cost and scarcity of such fuels, greater attention is now being paid to cogeneration systems using refuse-fired incinerators and industrial waste heat such as that from pulp mill bark burners. District-heating systems operating in conjunction with fossil-fuelled steam power plants have increased the efficiency of fuel use by about 143 per cent. For 100 units of heat used in a cogeneration system, up to 20 units may be lost in the boiler and 5 in the distribution system, leaving 25 units of high-grade energy in the form of electricity and 50 units of low-grade district heat. Nuclear power stations have also been considered as sources for district heating.

Due to their dependence on imported oil, Sweden, Denmark, and West Germany lead in the development of district heating outside Eastern Europe and the Soviet Union. In Sweden, about 35 towns have district-heating systems, of which the largest, in Stockholm, serves only a small percentage of all city buildings, but it is one of the largest district-heating and power systems outside the Soviet Union. The system incorporates temporary boilers serving new communities, regional heating plants, and large heat and power generating stations. The Hogdalen refuse disposal plant producing electric power (15 to 20 MW) and hot water heat (60 to 70 MW) illustrates the use of alternative fuels in this system.

Four Swedish towns with populations between 80 000 and 100 000 have district-heating systems serving more than 60 per cent of their population. In Vasteras, 95 per cent of all buildings are connected to the system. Shortage of capital funds has been the major obstacle to an even more comprehensive development of district heating in Sweden.

Various inducements, including direct government subsidies for retrofit connections and linking of approval for building permits to the connection of district heating, are applied to persuade customers to use district heating. New subdivisions or housing developments within reach of a district-heating system are almost invariably connnected from the start. Often a temporary oil-fired hot-water boiler is used for several years until lines from the main plant are extended to the new areas, or until the heating load increases to a magnitude that can economically sustain a larger permanent heating plant. The temporary boilers then provide emergency standby or peak-capacity requirements, or are moved to other new outlying subdivisions. Permanent heating plants, each serving a specific part of the community, are interconnected. Eventually heating demand can justify a large combined heating and power-generating plant.

North American Experience

Substantial sections of the downtown areas of New York, Philadelphia, Boston, and Detroit have central steam heat. Ottawa, Toronto, London, and Vancouver also have district-heating systems. Downtown Toronto is presently integrating a number of localized district-heating systems in order to better use heat produced from the burning of municipal waste. A similar proposal is being considered for the downtown areas of Ottawa and Hull. Urban renewal schemes that include the conversion of older power-generating plants into sources of district heating are being considered in Halifax and Edmonton.

Municipal refuse is becoming a source for heat and power generation: district heating helps defray the costs of incineration now that, for ecological reasons, garbage is becoming less acceptable as landfill.

Mississauga, Ontario

Mississauga recently completed a study of its downtown core area which projects a 20 per cent energy saving through the use of district heating and a further 35 per cent reduction through district cooling in the city. The density and street patterns of the core area make this feasible.

LeBreton Flats, Ottawa, Ontario

Whereas steam or high-temperature hot water is the principal transport medium in North American district heating systems, LeBreton Flats in Ottawa uses a low-temperature hot-water system with a gas-fired central boiler to provide 197 townhouses and apartments with space heating and hot water. LeBreton Flats is a demonstration project that will measure how much energy can be saved with district heating as compared to conventional systems.

Shenandoah, Georgia

Shenandoah carried out a feasibility study into district heating and found that a central plant could conserve energy (through more efficient use of primary fuels), stabilize energy costs, and save money for residents. The recommended system used a small central utility plant, phased to serve the site as it develops. The plant would produce thermal energy for heating and cooling, and electricity for power. The six fuel combinations evaluated were fuel cell; internal combustion engine with heat recovery; wood-fired thermal; photo-voltaic; solar thermal central plant; and solar thermal/electric. Of these, a wood-fired electrical co-generation system was found to be the most suitable alternative. No cost-benefit details are available for this investigation.

Pickering, Ontario

In a study for a new town at Pickering, Acres Shawinigan Limited (1976) evaluated four alternative methods for district heating and compared them with conventional independent heating systems. They found that a combined district-heating and power-generation system (the least wasteful and most advanced technology available using fossil fuels) was not competitive with a single-purpose, centralized, high-temperature, water-heating system. This was because the cost of the power produced by cogeneration was higher than the power rates in Ontario at the time of the study.

The theoretical study used Pickering, Ontario, as a site and evaluated alternatives over a life cycle of 40 years (Table 4). Despite higher capital costs, overall costs for the fossil-fuelled high-temperature (176°C) water-heating system balanced conventional heating costs in 15 years, whereas the nuclear system needed 17 years. The projected cost of fuel for the fossil-fuelled system was two-thirds less than the conventional system in 1990; the nuclear fuel was five times less.

The projected overall costs for the fossil-fuelled system and nuclear cogeneration system were 43 and 24 per cent, respectively, of the projected forty-year life cycle costs for

Table 4. Comparative annual costs* of conventional and district heating systems

Year	Capital			Maintenance			Labour			Fuel			Pumping distribution			Total		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1978	0.07	7.07	6.70	0.01	0.14	0.13	0.09	0.05	0.05	0.79	0.48	0.48	N.A.	0	0	1.59	7.74	7.15
1980	2.0	29.45	30.97	0.07	0.76	0.77	0.60	0.23	0.23	5.12	3.09	3.09		0.04	0.08	7.79	33.58	35.13
1982	3.4	34.32	36.08	0.21	1.55	1.62	1.70	0.55	0.55	13.34	8.10	8.09		0.10	0.18	18.65	44.62	46.52
1984	4.2	8.05	7.67	0.41	1.94	2.01	2.90	0.63	0.63	23.50	41.11	14.10		0.12	0.22	31.01	24.85	24.63
1985	5.5	2.82	2.58	0.55	2.13	2.18	3.90	0.80	0.80	30.59	18.31	18.38		0.14	0.25	40.54	24.20	24.20
1986	6.2	9.09	8.66	0.71	2.40	2.45	5.00	0.86	0.86	38.72	23.23	23.23		0.14	0.26	50.63	35.72	35.46
1988	7.5	48.46	218.16	1.12	3.79	7.96	7.80	1.39	1.39	58.66	35.09	15.56		0.23	0.41	75.08	88.96	243.48
1990	6.1	54.21	56.76	1.51	5.42	10.08	10.50	1.95	1.95	77.02	46.20	18.50		0.33	0.60	95.13	108.11	87.89
1992	5.6	13.02	12.39	1.95	6.46	11.57	13.80	2.23	2.23	98.34	59.07	18.67		0.33	0.59	119.69	81.11	33.29
1995	0	0	0	2.36	7.92	13.78	16.90	2.72	2.72	115.47	69.31	15.46		0.31	0.55	134.73	80.26	32.52
2000				3.23	11.11	18.43	23.70	3.83	3.83	150.90	90.59	20.16		0.34	0.60	177.83	105.87	43.02
2005				4.43	15.58	24.67	33.30	5.37	5.37	197.23	118.40	26.28		0.44	0.79	234.96	139.79	57.11
2010				6.07	21.85	33.01	46.70	7.54	7.54	257.78	154.74	34.27		0.57	1.03	310.55	184.70	75.85
2015				8.32	30.64	44.18	65.46	10.57	10.57	336.91	202.24	44.67		0.74	1.34	410.69	244.19	100.76
2020				11.40	42.98	59.12	91.82	14.82	14.82	440.34	264.32	56.85		0.97	1.75	534.56	323.90	132.54
2022				12.93	49.21	66.43	105.12	16.97	16.97	490.13	294.19	62.32		1.08	1.94	608.18	261.45	147.66

A - Conventional independent heating systems (50% oil, 50% natural gas).
B - Fossil-fuelled high-temperature water-heating system.
C - Nuclear cogeneration.
* Millions of dollars.

Source: Acres Shawinigan (1976).

the independent systems. The nuclear alternative cost 56 per cent of the conventional fossil-fuelled district-heating system.

Conclusions

The use of district heating to supply neighbourhood heating requirements should be compared, in terms of costs and benefits, to conventional independent heating systems. District heating is found to have more stable pricing (i.e. it is less responsive to fluctuations in energy prices) for space conditioning and domestic hot-water heating. It also has the potential to use low-grade fuel sources rather than fossil fuels and electricity. In many cases, such as cogeneration using garbage incineration or nuclear plants, major benefits accrue in terms of combined efficiencies of operation.

The high capital costs of district-heating systems and transmission heat losses which reduce efficiency are more than counterbalanced by fuel savings and energy security over the life of the system.

1. District heating can save 50 to 75 per cent of the cost of space conditioning (heating and cooling) and domestic hot-water heating over a life cycle of 40 years, assuming the use of the most economical fuel alternative.
2. District heating should be used in conjunction with medium residential density (67 to 94 du/ha) housing. Compact development improves heat transmission efficiencies. Mixed-use development with different peak demands also improves energy efficiencies.
3. The district-heating system should be tailored to local opportunities including local sources of energy such as fossil fuels, nuclear, solar and biomass, and cogeneration with electricity generation or industrial uses. Cogeneration of electricity can improve total fuel use by 50 per cent.
4. District heating should use flexible systems which accommodate community growth and change. Portable plants might be used in new developments until a permanent district-heating plant is economical.

ENVIRONMENTAL DESIGN

Environmental design practices can save significant amounts of the energy required for site development and maintenance, residential space heating and cooling, water heating, lighting, and transportation. Embodied energy, or the energy used to construct roads, buildings, and landscaping, can be reduced 15 to 25 per cent; while operational energy, the energy used to heat and cool residences and run cars, can be reduced by 10 to 50 per cent. Most embodied energy savings are expressed in terms of cost savings.

Principles

Environmental design seeks the best fit between a site and the site development program, including site and building design, in order to maximize the suitability and minimize the impact of new development. This process of achieving a good fit between the development program and the site involves three major stages (Figure 14); analysis, synthesis, and implementation:

1. Analysis of site development opportunities and constraints, such as geotechnical, climatic, solar, topographic, biotic, and cultural factors;

2. Design synthesis, fitting the development program to the site opportunities and constraints with consideration of cost and energy use contraints; and

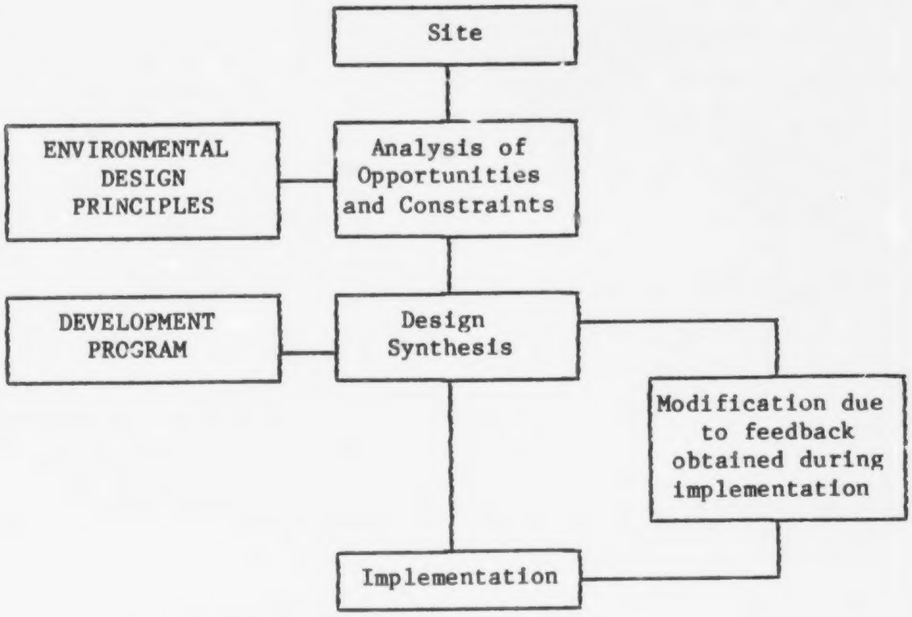
3. Implementation of the site plan and engineering design ensuring that construction practices respond to site conditions and minimize impact.

Determination of the site opportunities and constraints requires a site survey and analysis, and mapping of the general constraints. Geotechnical factors affecting engineering and foundation costs are especially important in residential development. These include soil type, permability, bearing capacity, slope stability, surficial geology, bedrock geology, groundwater hydrology, and surficial drainage patterns. Climate, topography, vegetation, and cultural features are other important considerations in site development.

Environmental design is a process through which small expenditures for site analysis and development planning produce significant cost and energy savings. Tailoring the development program to the site through the design synthesis requires trade-offs between development objectives and site conditions. The principles of the design synthesis are:

- overall planning to maintain existing landforms, slopes, drainage patterns, and vegetation, thereby reducing the energy expended in stripping vegetation and topsoil, earthwork, erosion control, and future landscaping
- specific siting of buildings and roads to minimize cut-and-fill

Figure 14. Environmental design


Site
ENVIRONMENTAL DESIGN PRINCIPLES
Analysis of Opportunities and Constraints
DEVELOPMENT PROGRAM
Design Synthesis
Modification due to feedback obtained during implementation
Implementation

- keeping road and utility lines short to minimize site disruption
- siting buildings to use existing vegetation and topography as buffers against cold winter winds and as channels for cooling summer breezes, and
- considering the effect of vegetation and topography on siting buildings for solar access.

Construction practices which minimize earth moving and soil exposure, and reduce erosion through diverting and slowing runoff, save energy both in site development operations and in the preservation of topsoil which would otherwise have to be imported. Similarly, maintaining areas of existing vegetation through careful construction management will reduce future landscaping requirements.

Examples

Burke Center, Virginia

A study in Burke Center Community (Appendices I and II) compared energy-conserving and conventional plans on the same parcels of land, in terms of site development costs and residential, commercial, and recreational energy use. The energy-conserving test parcels produced an overall saving of 24 per cent in land development costs. The principal savings were in paving, earthwork, and utility line reductions, and are easily related to energy savings (Table 5).

The Burke Center energy-conserving plan reduced residential energy use, including space heating and cooling, water heating, lighting, and appliances, by 35 per cent (Table 6). This was achieved through the application of energy-saving measures appropriate to the particular site and context. A specialized technical team pre-selected the following conservation measures for Burke Center:

- building orientation to take advantage of the effects of sun and wind
- clustering and consolidation of buildings for sun and wind control, and overall reduction of exterior wall areas
- natural screening with earth berms and vegetation
- water-to-air heat pumps
- water-saving devices, and
- reduction of transportation energy requirements through development of a more efficient circulation system.

The study also indicated that maximum yield and maximum profit are not always synonymous. In one test parcel, a 3 per cent reduction in the number of dwelling units proposed in the

Table 5. Comparative site development costs for Burke Center

Item/Description	Conventional Plan	Energy Plan	
	Total cost ($000)	Total cost ($000)	Percentage saving per item (%)
Site preparation	351	358	-2
Earthwork	2 651	1 537	42
Erosion control	55	49	11
Site drainage	669	545	19
Sanitary sewer	526	424	19
Water line	535	372	30
Pavement	3 547	3 045	14
Curb/Gutter	687	345	50
Shade trees	246	375	-34
Evergreen trees	10	15	-33
Shrubs	27	27	0
TOTAL	9 304	7 092	24

Source: Urban Land Institute (1981).

Table 6. Comparative operating energy use for Burke Center

Item/Description	Conventional Plan	Energy plan	
	Total energy use (10^9 KJ/yr)	Total energy use (10^9 KJ/yr)	Percentage saving per item
Heating, ventilation air conditioning, lighting, appliances and hot water	144.6	99.4	31.3
Transportation:			
on-site	101.5	98.5	3.0
off-site	381.1	374.9	1.6
Potable water treatment	15.9	9.1	42.8
Waste-water treatment	28.6	16.4	42.7
Refuse collection and disposal	3.1	1.8	41.9
TOTAL	674.8	600	

	Operational energy (10^9KJ/m^2/yr)	Operational energy (10^9KJ/m^2/yr)	
Residential operational energy use index*	545 591.9	369 167.7	35

*Includes HVAC equipment, lighting, hot water heating, and pumping energy uses.

Source: Urban Land Institute (1981).

conventional plan gave rise to development cost savings of 36 per cent in the energy-conserving plan.

Radisson, New York

In Radisson, energy-conservation plans (Appendix III) incorporated passive-solar features of site design similar to those of Burke Center, including:

- building orientation at a 90-degree angle to the prevailing winter winds
- buffering of winter winds by vegetation, unit clusters, and solid fences
- selection of residential sites on slopes that maximize solar radiation (southeastern being considered most desirable)
- orientation of the largest window areas to maximize solar exposure in the heating season and minimize mechanical heating and cooling requirements, and
- clustering of single-family attached and detached units on private drives to optimize wind protection and solar orientation.

Mechanical systems which would heat, cool, and provide domestic hot water to the Radisson units included three alternatives: independent systems such as air-to-air and groundwater heat pumps, or solar panel with thermal storage for individual buildings; cluster systems; and a central plant system.

Possible savings through wind protection was simulated by a model which identified annual energy savings of between 6 and 9 per cent for single-family detached units and up to 13 per cent for townhouse units. An overall comparison of an energy-conserving plan with the conventional site plan (Table 7) indicated that 70 per cent of the north and west surface wall exposure on the conserving plan is sheltered from the winter wind compared to 20 per cent on the conventional plan. The distribution of surface walls by orientation indicated that the energy conserving plan reduced north wall exposure by 2 per cent and east/west wall exposure by 37 per cent. Prevailing winter winds are from the northwest in Radisson, with an average speed of 16 km/h. Radisson has 3 692 HDDs and 288 cooling degree days, annually (Appendix IV).

Radisson produced overall savings per unit in site development costs for each alternative energy plan (Tables 8 and 9). Although overall costs were 6 per cent higher for energy-conserving plan #1 and less than 1 per cent lower for plan #2, development costs per unit were respectively 17 and 9 per cent less than the conventional plan. Approximately the same

Table 7. Housing unit operating costs due to wind exposure, for Radisson

Item/description	Conventional plan	Energy plan #1	Energy plan #2
Overall operating costs ($)			
unprotected units	54 468	24 938	20 581
protected units	22 695	69 163	61 107
TOTAL	77 163	95 101	81 688
Number of units			
unprotected	137	66	52
protected	64	193	163
TOTAL	201	259	220
Operating costs per unit ($)	383.9	367.2	371.3
Energy savings (%)	0	4.4	3.3

Table 8. Cost comparison for residential development in Radisson

Item/Description	Conventional Plan	Energy Plans			
		Plan #1		Plan #2	
	Total cost ($)	Total cost ($)	Savings (%)	Total cost ($)	Savings (%)
Roads/driveways					
(overall plan)	593 000	530 000	10.6	577 000	2.7
(per unit)	2 950	2 046	30.6	2 622	11.1
Water	238 000	236 000	0.8	231 000	2.9
	1 184	911	23.1	1 050	11.3
Sanitary sewers	425 000	462 000	-8.7	420 000	1.2
	2 114	1 784	15.6	1 909	9.7
Drainage*: piping	160 000	291 000	81.9	177 000	10.6
ditching	52 000	52 000	0	52 000	0
	259	201	22.4	236	8.9
Walkways	225 000	225 000	0	225 000	0
	1 119	869	22.3	1 023	8.6
Contingencies	253 950	269 000	-5.9	252 300	0.8
	1 263	1 038	17.8	1 146	9.3
TOTAL OVERALL	1 946 950	2 065 000	-6.1	1 934 300	0.6
PER UNIT	9 686	7 973	17.7	8 792	9.1

* Difference in cost between piping and ditching operations is due to increased pipe size for energy plans, required because of increased density.

Table 9. Comparison of residential embodied energy for Radisson

Item/Description	Conventional Plan	Energy Plans Plan #1		Plan #2	
	Total energy use $(10^{6}$kj/yr$)$	Total energy use $(10^{k}$j/yr$)$	Savings (%)	Total energy use $(10^{k}$j/yr$)$	Savings (%)
Roads/driveways					
(overall plan)	8 415	7 967	5.3	8 320	1.1
(per unit)	42	31	26.2	38	9.5
Water	4 513 24	3 904 15	13.5 37.5	4 450 20	1.4 16.7
Sanitary sewers	3 624 18	3 693 14	-1.9 22.2	3 502 16	3.4 1.1
Drainage*: piping	3 891 19	4 959 19	-27.4 0	3 222 15	17.2 21.1
ditching	30 0.15	30 0.12	0 20.0	30 0.14	0 6.7
Walkways	633 3	633 2	0 33.3	633 3	0 0
Contingencies	3 165 16	3 177 12	-0.4 25.0	3 023 14	4.5 12.5
TOTAL OVERALL PER UNIT	24 271 122	24 361 93	-0.4 23.8	23 180 106	4.5 13.0

* Difference in cost between piping and ditching operations is due to increased pipe size for energy plans, required because of increased density.

embodied energy (±5 per cent) was consumed in each of the plans, but on a dwelling unit basis, embodied energy decreased by 22 and 12 per cent in energy-conserving plans #1 and #2, respectively. The developer increased his profit per lot by $1 274 in energy-conserving plan #1 and $870 in Plan #2 while reducing operating costs per unit (Appendix V). The savings due to the application of energy-conserving techniques in Burke Center and Radisson are summarized in Table 10.

Guelph, Ontario

Sheltering can have a major impact in high wind situations. For a detached unit in Guelph, Ontario (Ontario Ministry of Housing, 1981) heat losses were 19.4 per cent greater with a wind of 11 km/h than with no wind, and 38.3 per cent greater with a wind of 24 km/h.

Conclusions

Environmental design recognizes that every development is unique. Physical conditions vary between individual sites, and so do development programs, according to the developer's objectives, market trends, development regulations, and technical know-how. The following approaches have demonstrated energy savings under a variety of conditions.

1. Environmental design practices will produce savings in the order of 15 to 25 per cent of embodied energy in areas with physical constraints such as steep slopes, dense vegetation, or existing structures.

2. Energy expended in the operation of equipment for grading, demolition, or clearing can be minimized through well-designed lot layouts and grading, and the incorporation of existing structures into the plan.

3. The use of open space as natural drainage channels, the reduction of runoff through the use of on-site percolation basins, and the use of permeable paved surfaces will all serve to avoid equipment operation and use of materials (embodied energy) for creating stream channels, water-control structures, and other improvements to storm drainage.

4. The preservation of existing vegetation may be in the form of managed wood lots in open spaces that can serve as alternative fuel sources.

5. Embodied energy for construction of streets and utilities will be reduced through efficient site design which minimizes the length of streets and utility lines.

Table 10. Summary of site costs due to the application of energy-conserving techniques in Burke Center and Radisson

Item Description	Site development costs	Net savings of energy plans over conventional plans %
	(Total cost $)	
Burke Center		
Conventional Plan	9 304 000	
Energy Plan	7 092 000	24
Burke Center Parcel 22		
Conventional Plan	2 541 000	
Energy Plan	1 570 000	38
Radisson		
Conventional Plan	1 946 950	
Energy Plan #1	2 065 000	- 6.1
Energy Plan #2	1 934 300	0.6
	(Cost per du $)	
Burke Center Parcel 22		
Conventional Plan	5 993	
Energy Plan	3 829	36
Radisson		
Conventional Plan	9 686	
Energy Plan #1	7 973	17.7
Energy Plan #2	8 792	9.1

Table 10. Summary of site costs due to the application of energy-conserving techniques in Burke Center and Radisson (Cont'd)

Item Description	Energy use	Net savings of energy plans over conventional plans %
	(Total embodied energy use 10^6kJ/yr)	
Radisson		
Conventional Plan	24 271	
Energy Plan #1	24 361	- 0.4
Energy Plan #2	23 180	4.5
	(Embodied energy use per du)	
Radisson		
Conventional Plan	122	
Energy Plan #1	93	23.8
Energy Plan #2	106	13
	(Residential operational energy use index 10^6 kJ/m^2/yr)	
Burke Center		
Conventional Plan	545 591 900	
Energy Plan	369 167 700	35

Table 10. Summary of site costs due to the application of energy-conserving techniques in Burke Center and Radisson (Cont'd)

Item Description	Energy use	Net savings of energy plans over conventional plans %
	(Operating energy use 10^6kJ/yr)	
Burke Center		
Conventional Plan	674 800	
Energy Plan	600 000	11
	(Operating costs total costs $)	
Radisson		
Conventional Plan	77 163	
Energy Plan #1	95 101	23
Energy Plan #2	81 688	-5.8
	(Cost permit $)	
Radisson		
Conventional Plan	383.90	
Energy Plan #1	367.20	4.4
Energy Plan #2	371.30	3.3

6. Residential development in areas with favourable microclimate will save operational energy. Siting buildings in areas with south-facing slopes, and providing protection from winter winds and access to summer breezes will save 10 to 35 per cent of operational energy requirements.

7. Microclimate conditions may be improved through the following measures:

   - orienting lots and buildings to the south or southeast
   - providing wind breaks against winter winds
   - planting street trees
   - imposing restrictions on lot coverage for unshaded paved surfaces
   - using water areas for modification of the climate, and
   - providing a manual for lot buyers on proper orientation and landscaping.

8. The use of building materials that do not take much energy to manufacture, especially local materials with small transportation costs, will reduce the consumption of embodied energy.

9. Energy required to maintain landscaping through mowing or irrigation will be reduced by keeping lawn areas to a minimum and selecting low-maintenance, climate-adapted plantings or maintaining existing areas of vegetation.

PASSIVE SOLAR ENERGY

Passive solar energy can contribute 10 to 40 per cent of a building's space-heating requirements depending on housing quality, siting, and location. Unless the cost of achieving this gain is minimal, however, solar heating is less cost-effective than other neighbourhood-level energy-conserving techniques. Design for solar energy is generally an extra cost, and does not have strong market attraction.

Gough (1979) indicates that passive solar gain through the window areas of the existing stock of residential buildings accounts for 12.5 per cent of the gross annual energy requirement for residential heating. This means solar heat gain presently accounts for 2.26 per cent of Canada's total annual energy consumption. Proper planning of windows can significantly increase this total.

Principles

As the thermal efficiency of the building envelope is improved the actual marginal contribution of environmental design for solar orientation, buffering winter winds, and channelling summer breezes becomes less significant. This is because the heating season of an airtight, super-insulated house is much shorter (three months) than for a conventional house (six months). Thus additional costs incurred in the collection of solar energy or in wind buffering must be balanced against very small incremental energy savings.

Passive solar systems include direct-gain systems, with incremental costs up to 10 per cent of the cost of building construction ($6 000), and Trombe-wall and water-wall systems, which add 5 to 12 per cent ($3 000 to $7 200) to residential construction costs. The direct-gain system is the simplest and most commonly used.

During the heating season, the direct-gain system allows sunlight to enter a building directly through sun-oriented windows or skylights. When sunlight falls on floors and walls, part is absorbed and stored as thermal energy, and part is converted directly to heat. If the structure is properly designed for passive solar heating, the floors, walls, and ceilings will reach a maximum temperature of between 26 and 27°C. When the room temperature drops below the temperature of this thermal mass, or when people or objects in the room are cooler than this temperature, the floors, walls, and ceilings act as large low-temperature radiators. Radiant heating is one of the most efficient and comfortable means of heat transfer.

Housing which uses direct-gain solar heating requires correct orientation of windows and unobstructed solar skyspace within the critical hours of sunshine (09:00 to 15:00 hr) during the heating season. This is the period in which the sun has an altitude of 10 degrees or more above the horizon and is suitable for passive solar heating in the coldest months (Figure 15 and 16). At a latitude of 44°N, 90 per cent of the sun's useful energy occurs between 09:00 and 15:00 hr but, at higher latitudes this period of useful sunshine gets shorter. Solar gain is possible up to about latitude 59°N, and is most useful during the spring and fall (*see* Map 1).

Although optimum solar orientation varies according to climatic zones, that in Canada is generally south or within 15° east of south (the more easterly orientation allows sun to enter a building earlier in the morning when heat is most needed after a cold night). Orientations up to 22.5 degrees east or west of south will achieve substantial solar gain (Figure 17). The

Figure 15. Azimuth and Altitude.

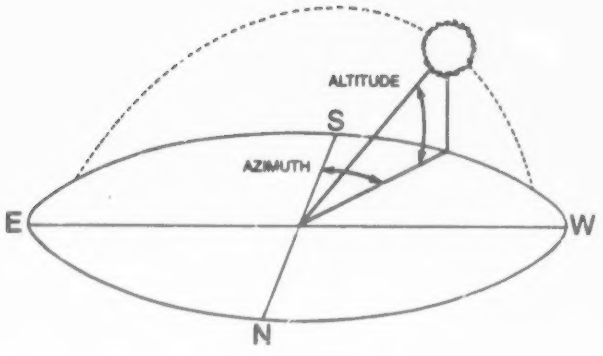
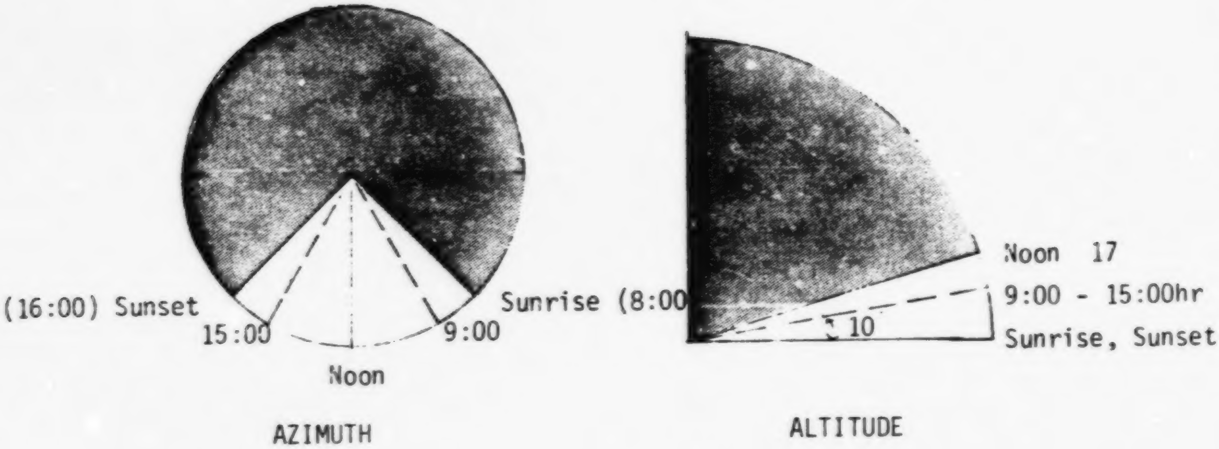
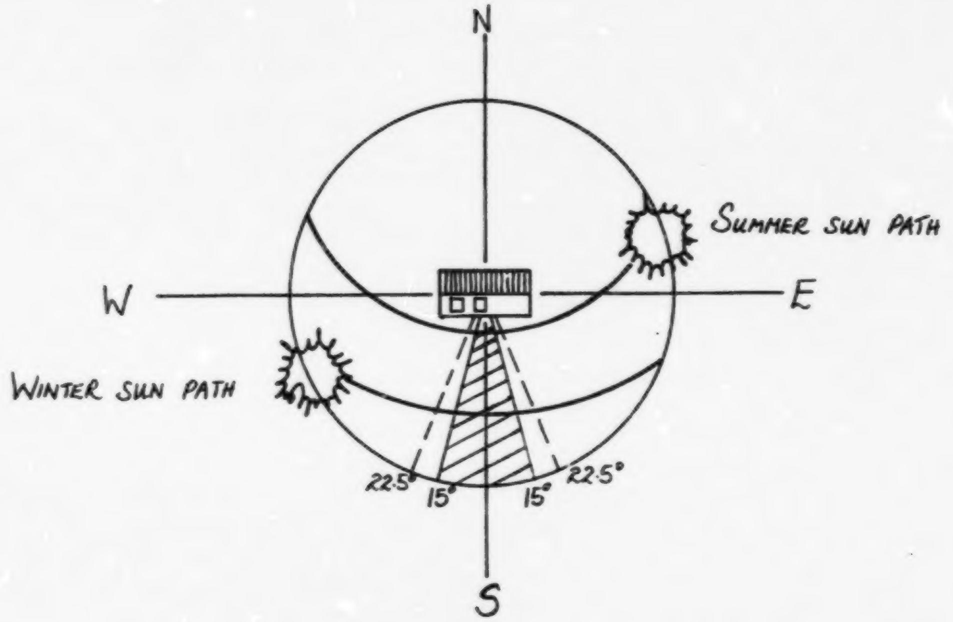

ALTITUDE
S
AZIMUTH
E
W
N

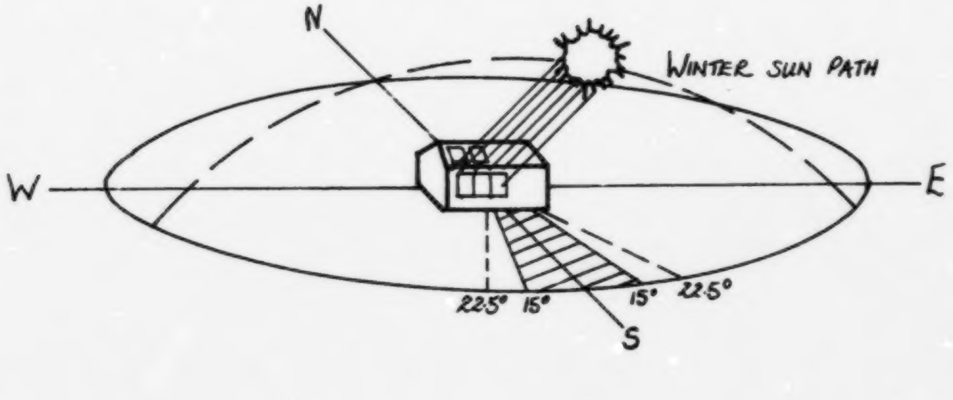
Figure 16. Critical hours of sunshine.


(16:00) Sunset
15:00
Noon
9:00
Sunrise (8:00
AZIMUTH
Noon 17
9:00 - 15:00hr
10
Sunrise, Sunset
ALTITUDE

(Data for 50°N latitude, December 21)

Figure 17. Optimum solar orientations.


N
SUMMER SUN PATH
W
E
WINTER SUN PATH
22.5°
15°
15°
22.5°
S


N
WINTER SUN PATH
W
E
22.5°
15°
15°
22.5°
S

Frankel/Lambert Townhouse Development in Toronto, Ontario measured 45 per cent higher solar gains in south-oriented units than in east- or west-facing units. This reduced the requirement for heating fuel in south-facing units by an estimated 12.5 per cent.

Proper solar orientation for direct-gain heating requires consideration of street and lot layout, building siting, and building design including:

- east-west street orientation ensures that standard lotting is oriented south or within 15° of south
- lot orientation through the use of angled lot lines, flag lots, or corridor lots to ensure southerly orientation where streets are not oriented east-west
- building setbacks, height, and design to ensure that buildings do not block the solar skyspace of other residences, and
- building siting and design to orient the greatest areas of windows south while minimizing other window areas.

Since conventional lotting in subdivisions is perpendicular to the streets, good solar orientation is ensured by running residential streets east-west, or 15° north or south of east-west. This is the most commonly implemented solar design technique at the neighbourhood scale and is used in solar subdivisions from California to Ontario.

Regulations for solar orientation requiring a minimum proportion of east-west streets in future subdivisions must permit exceptions, however, to account for other potentially conflicting energy-conserving strategies; for example, designing in response to topography which slopes from east to west.

Solar access may also be affected by decreasing right-of-way widths that reduce the solar setbacks between residences across the street from one another. Wide streets and rights-of-way, on the other hand, use more energy to construct and maintain, cause excess runoff, and increase air temperature in summer. If a reduction in street width would have a negative impact on solar access, then other measures, such as increasing front yard setbacks, might be employed to ensure solar opportunities.

Where subdivision regulations require lot lines perpendicular to streets, the orientation of lots will be governed by street orientation as opposed to solar access requirements. On east-west streets this ensures optimal solar access and flexibility in building siting; however, where the street axis shifts to a north-south or intercardinal direction, perpendicular lot lines often mean poor orientation.

Streets running southeast to northwest with perpendicular lot lines could lead to residential overheating in summer. A better approach would be to angle the lots to the street so that their axes are north-south (Figure 18), taking care that residences do not shade each other's solar skyspace. A simple check is to draw the 45-degree azimuth lines defining solar skyspace to ensure that buildings are not shading the south-facing walls of their neighbours in the critical hours of heating.

Solar orientation of lots on north-south streets, or on intercardinal streets along which lots cannot be angled, can be maintained by combining lots, using flag or key lots, and increasing lot frontage (Figure 19). The first is especially useful where a lot layout has already been dictated: two lots abutting north and south can be combined and buildings sited close by each other along an east-west axis. This could necessitate use of semi-detached or unconventional housing forms and revisions to city subdivision standards or zoning bylaws. The flag, or corridor access, works in a similar fashion but with a designated access corridor from the interior lot to the street. Key or chevron lots are a variation on this theme with the house in one corner of the L-shaped lot with front yards at right angles to rear yards.

Regulating building setbacks on lots which are oriented east-west or intercardinally will allow residences at least to experience southern exposure for part of the day (Figure 20). This approach, using PUD or zero lot line regulations, may be the only one that can be used to gain some of the benefit of solar access with certain site constraints such as easterly sloping topography.

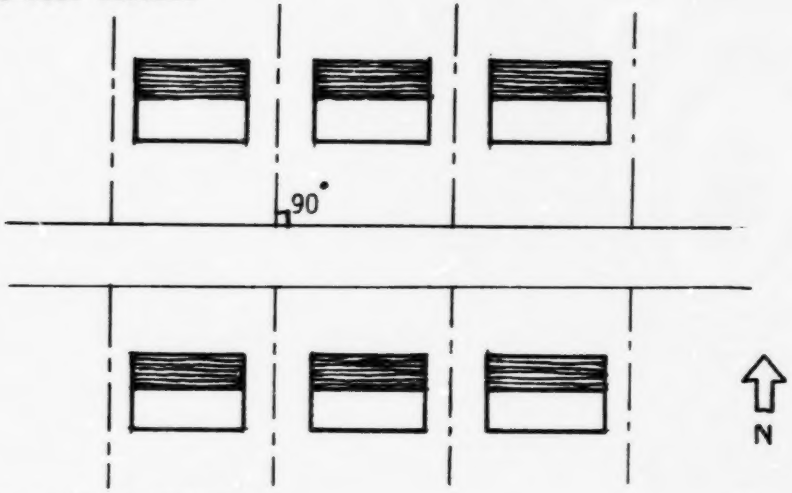
Building setbacks on lots are important even on conventional north-south lots (Figure 21). If south-entry units do not have uniform front yard setbacks, and north-entry units uniform rear yard setbacks, then certain houses will lose part of their solar access.

Alternative housing types may be necessary in some cases to maximize solar access. A performance standard requiring a certain minimum level of solar orientation for lots promotes solar access and leaves developers and planners the freedom to choose their own layout for streets, lots, and buildings. The major disadvantage of this approach is the extra administrative time required in reviewing plans and applications to determine their compliance with the performance standards.

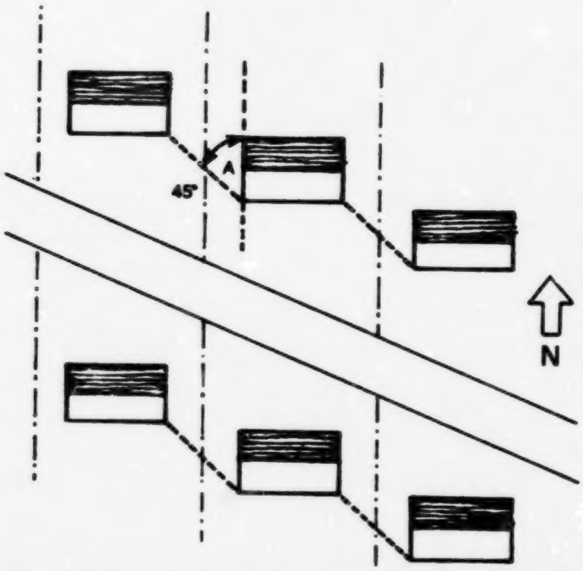
Landscaping also affects solar access. If a municipality requires boulevard tree plantings and site landscaping, the landscape plan should not hinder solar access to residences. An

Figure 18. Lot orientation on (from Erley and Jaffe, 1979).

(a) east-west streets



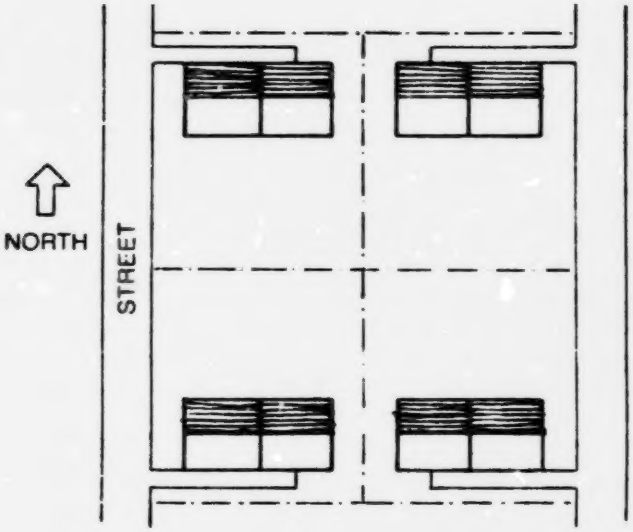
(b) intercardinal streets



Maintaining south orientation of housing where streets are shifted from the east/west axis. Angle A is formed by the intersection of north/south with a line connecting the southwest corner of one house to the southeast corner of its western neighbor.

Figure 19. Combining lots and using flag lots for proper orientation on north-south streets (from Erley and Jaffe, 1979).

(a) combined lots


NORTH
STREET

(b) flag lots

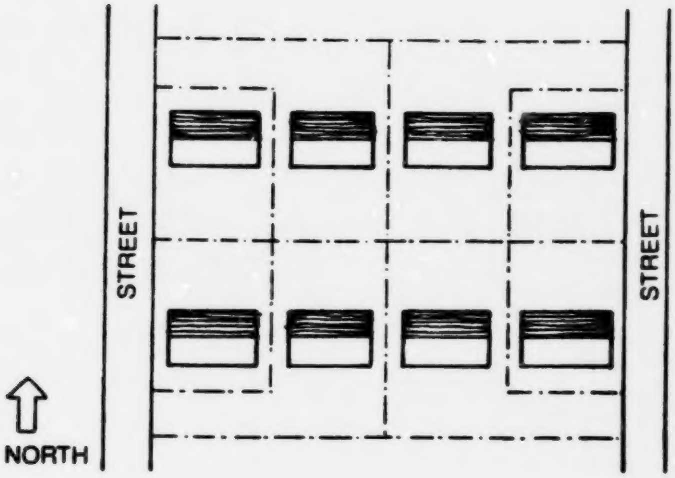

STREET
STREET
NORTH

Figure 20. Uniform versus staggered setbacks on north-south street.

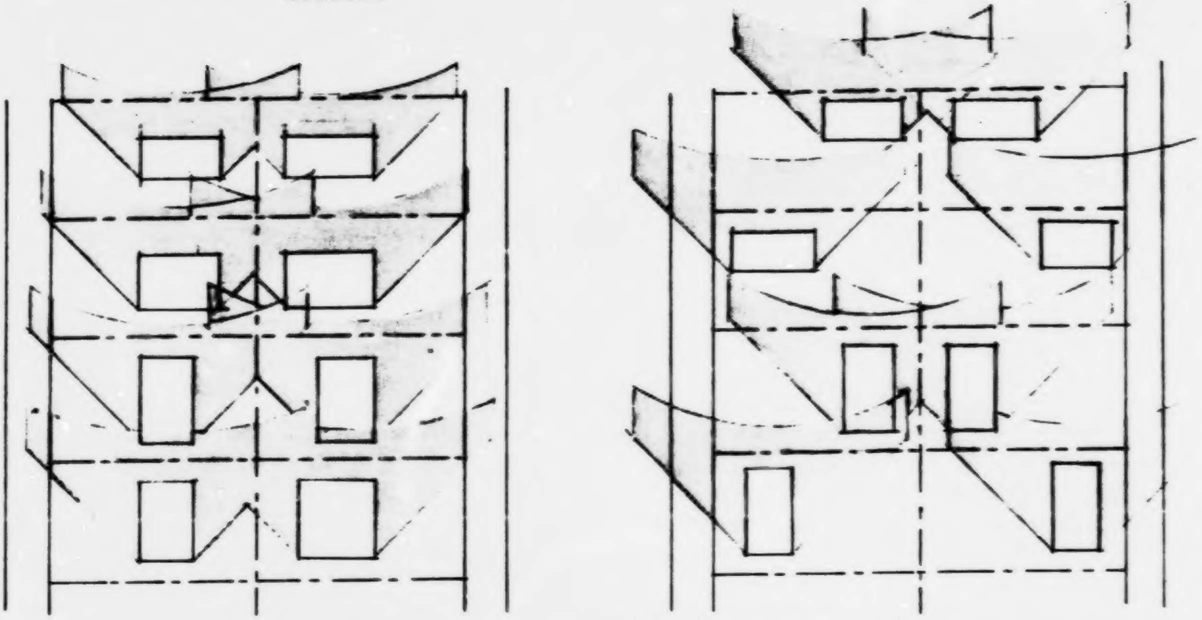
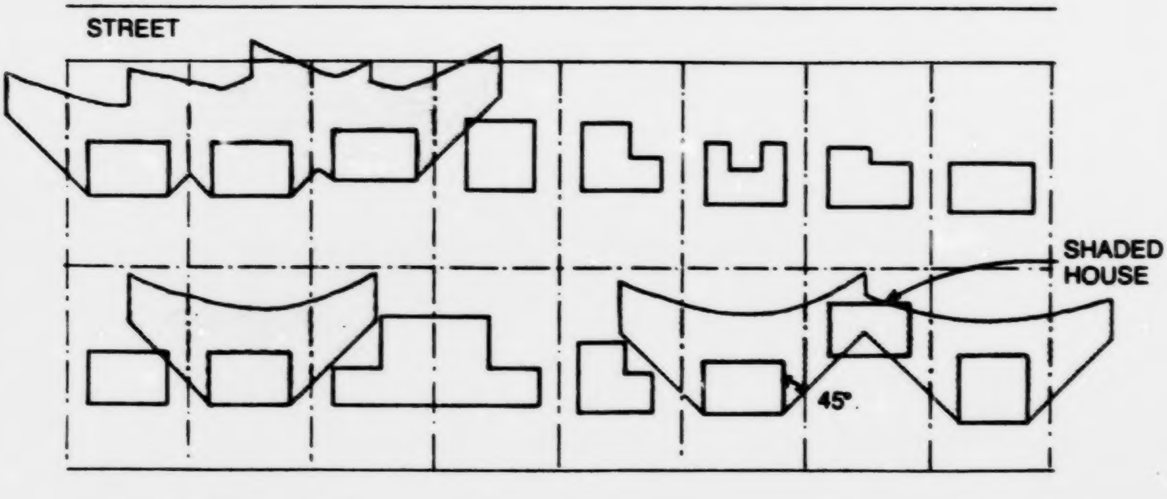


Figure 21. Uniform versus staggered setbacks on east-west street.


STREET
SHADED HOUSE
45°

ideal energy plan would develop coniferous buffer plantings to screen coldwinter winds, and deciduous plantings to shade surfaces and south-facing walls in the summer, yet allowing sun penetration during the heating season.

Examples

Sacramento, California

In late 1977, Sacramento adopted a resolution that new lots and residences be oriented for maximum potential use of passive solar energy. All new developments are evaluated for their solar orientation based on a performance standard for the orientation of lots. The long axis of all lots should be within 22.5 degrees of true north. The resolution made generous provisions for exceptions.

Alliance Subdivision, Brampton, Ontario

The Alliance Subdivision, designed under the 1979 Brampton Energy Conservation bylaw, represents a change to the conventional approach of subdivision design that is expected to save homeowners an estimated 10 per cent of residential energy costs.

The key changes made to the original design of the subdivision in order to incorporate direct-gain solar heating included:

- aligning streets east-west so that all lots face south
- designing each unit so that the main rooms are located on the south side of the house
- restricting building height to ensure that the shadow of each house falls either on yard space or a street, and not on the south wall of other homes
- where necessary, extending the roof overhangs to shield south-facing windows from the sun in summer while allowing full exposure in winter, and
- slanting roofs at an angle determined to provide maximum efficiency if a homeowner decides to install active solar panels for space or water heating.

Solar West, Vancouver, British Columbia

The Solar West development is designed to provide part of residential space-heating requirements through direct-gain solar heating. The development incorporates the following solar design strategies:

- locating units on south, south-east, or south-west facing lots to take advantage of the sun

- using lower buildings on the south side of streets and in the middle of housing rows to minimize shading of solar skyspace
- shaping streets to permit solar access to all residences, and
- relating residences to south-facing open space and developing shelter belts of trees and shade plantings.

Streets in Solar West are orientef 15° east of south to take advantage of the sun's heat in winter while avoiding summer overheating.

Tumbler Ridge, British Columbia

In Tumbler Ridge, a resource community in northern British Columbia, trade-offs have had to be made between buffering the prevailing winds and assuring solar access. Trees planted or retained as wind buffers could cause shadowing, but wind is continuous throughout the year, prevailing from the south and southwest at average speeds of 18 km/h. The designers recommended that major clusters of existing trees be preserved, especially along the south and southwest flanks of the town and in several locations interspersed throughout the townsite.

Other Examples

Whyte Ridge Residential Subdivision, Winnipeg, Manitoba, on an awkwardly shaped site, achieved an increase in solar orientation from 40 to 64 per cent with acceptable solar exposure. Figures of 85 per cent solar orientation have been achieved in areas such as Alliance Subdivision in Brampton, while Solar West in Vancouver has 80 per cent solar access. These examples assume no loss of lots due to the solar-oriented design.

Conclusions

Designing for passive solar heating requires consideration of the trade-offs in energy costs between all environmental design factors. Solar access regulations should be as flexible as possible to avoid unnecessary expenditures on development and lost opportunities for savings on environmental design through pursuit of ideal solar access. Flexible lotting and building siting will make up for streets which cannot be oriented east-west due to topography and other site constraints. The following points should be considered in conjunction with the previous conclusions on environmental design.

1. Designing for passive solar orientation can contribute 10 to 40 per cent of residential space-heating requirements at a cost of 0 to 10 per cent of the cost of residential construction.

2. Direct-gain solar access will ideally require windows oriented south or 15° east of south, and unobstructed by shadows between 09:00 and 15:00 hr during the heating season.

3. Flexible zoning regulations - based on performance standards - will ensure the best fit between solar access requirements and site conditions. Zoning regulations should encourage east-west or east-north-east to west-south-west street orientation, lotting on a north-south axis, and building siting or orient windows south or within 25.5 degrees east of south.

4. Where streets cannot be oriented east-west, design approaches which improve solar access include angling lot lines, combining lots, using flag or corridor lots, using key or chevron lots, and regulating building setbacks.

5. Solar zoning regulations will also eliminate shading from neighbouring structures or trees that could effect the use of direct-gain solar heating.

6. The potential improvement in solar orientation between conventional subdivision planning and developments planned for solar access ranges from 50 to 100 per cent.

NEIGHBOURHOOD ENERGY CONSERVATION CHECKLIST

Implementing the full range of neighbourhood energy-conserving principles requires a flexible process of administrative approval. Energy evaluation checklists have been developed in a number of municipalities in order to pinpoint unnecessary embodied or operational energy expenditure in neighbourhood development, and to suggest measures which would increase energy efficiency. Such checklists could become integral parts of the subdivision design process.

The following checklist was developed first, to summarize the main energy-conserving approaches, principles, and techniques at the neighbourhood level, and secondly, to indicate where energy savings or benefits will occur through their application.

Compact form, mixed land use, and environmental design are primary energy-conserving approaches. District and passive solar heating have a more restricted applicability. The use of an energy-saving technique in a given situation will depend on relative cost-effectiveness. The effect of energy requirements, opportunities, and constraints on energy conservation approaches is indicated at the end of Chapter 1.

Neighbourhood Energy Conservation Checklist

Approach	Principle	Technique	Potential savings and benefits
1. COMPACT FORM AND MIXED LAND USE	a. Locate development close to existing facilities and services.	i. Choose a site with convenient access to facilities and services: public transit, schools, parks, shopping, day care, library, fire protection, arterial roads, and major utilities.	- embodied energy for construction of roads and utilities. - operational energy for transportation operation and maintenance of roads and utilities, and transmission losses.
	b. Mix land uses in the development.	i. Develop a self-contained neighbourhood with all necessary facilities: commercial, recreational, and institutional.	- operational energy for transportation.
		ii. Encourage work in the home (cottage industry) and employment within the development.	- operational energy for transportation.
	c. Increase housing density to between 67 and 99 du/ha and create a more compact neighbourhood form.	i. Use higher-density housing forms: row-housing, walk-up apartments.	- operational energy for space conditioning. - embodied and operational energy for residential construction.
		ii. Create a planned unit development, reduce lot sizes and yard restrictions.	- energy for roads and utilities.
		iii. Cluster lots for detached homes.	- energy for roads and utilities.

Neighbourhood Energy Conservation Checklist

Approach	Principle	Technique	Potential savings and benefits
	d. Use efficient and innovative road and utility planning.	i. Develop an efficient road hierarchy to ensure smooth traffic flow and use computerized traffic signals.	- operational energy for transportation.
		ii. Minimize road and utility lengths through innovative planning.	- embodied and operational energy for roads and utilities.
		iii. Reduce pavement widths and develop neighbourhood parking bays.	- embodied energy for roads.
		iv. For efficient street lighting use high-pressure sodium lamps and space lamp standards further apart if consistent with public safety.	- embodied energy for lamp standards. - operational energy for lighting.
	e. Encourage more energy efficient modes of transportation.	i. Provide mass transit in conjunction with higher density and mixed land use.	
		ii. Develop bicycle paths and sidewalks to provide efficient, non-motorized access to facilities.	- operational energy for transportation.
2. DISTRICT HEATING	a. Evaluate the viability of district heating versus independent systems.	i. Use district heating in conjunction with higher-density housing (67 to 99 du/ha) and compact neighbourhood form.	- embodied energy due to shorter transmission lengths. - operational energy in transmission line losses.

Neighbourhood Energy Conservation Checklist

Approach	Principle	Technique	Potential savings and benefits
		ii. Use district heating in conjunction with high thermal density (use an energy audit).	- amortization period reduced for heating system.
	b. Use a flexible system to accommodate community growth and change.	i. Use portable plants in new developments until a permanent district heating plant is economical.	- low initial costs.
		ii. Interconnect district heating systems.	- energy security.
		iii. Provide for "District Cooling".	- operational energy for summer cooling.
	c. Tailor district heating system to local energy sources and opportunities.	i. Use alternative, low-grade energy sources such as biomass (wood) and solar energy.	- energy security. - operational energy.
		ii. Use in conjunction with cogeneration of electricity and use waste heat from industrial processes or incineration of garbage where possible.	- energy security. - operational energy.
3. ENVIRONMENTAL DESIGN	a. Prevent development on hazard lands.	i. Restrict development on steep slopes.	- reduced hazard of slumping.
		ii. Restrict development on flood-plains, bogs, and marshes.	- reduced hazard of flooding. - embodied energy for fill.

Neighbourhood Energy Conservation Checklist

Approach	Principle	Technique	Potential savings and benefits
		iii. Restrict development on poor soils for foundations.	- embodied energy. - reduced structural hazard.
	b. Maintain existing land-forms, slopes, drainage patterns and vegetation.	i. Minimize cut-and-fill by siting building and roads to fit local conditions.	- embodied energy. - savings in earthwork.
		ii.Use open space for natural drainage channels, percolation basins, and holding ponds, use permeable paved surfaces to reduce site runoff.	- embodied energy. - reduced need for site intervention and underground services.
		iii. Preserve existing vegetation to modify climate, or to be managed wood lots.	- operational energy in space heating and cooling. - energy source.
	c. Improve local microclimate.	i. Orient lot and buildings to the sun.	- operational energy. - solar heating.
		ii.Provide wind buffers for winter winds such as vegetation, fences, and buildings.	- operational energy for heating.
		iii. Channel summer breezes for their cooling effect.	- operational energy for cooling.
		iv.Impose lot coverage restrictions for unshaded paved surfaces.	- operational energy for cooling.

Neighbourhood Energy Conservation Checklist

Approach	Principle	Technique	Potential savings and benefits
		v. Use areas of water for climate modification.	- operational energy for cooling.
		vi. Provide a homeowners manual for proper house orientation and landscaping.	- operational energy for heating and cooling.
	d. Use energy-efficient, building materials, and local building materials.	i. Use natural materials such as earth, stone, and wood rather than high energy materials such as steel and plastics.	- embodied energy used in the production of building materials.
		ii. Use locally available building materials.	- operational energy for transportation of materials.
	e. Minimize neighbourhood maintenance requirements.	i. Preserve existing landscape.	- operational energy for new landscape endeavours.
		ii. Use low-maintenance climate-adapted plants.	- operational energy for maintenance.
		iii. Channel winds to keep snow off major streets.	- operational energy for snow clearing.
4. PASSIVE SOLAR HEATING	a. Orient major areas of glazing for passive solar gain.	i. Orient major areas of glazing south or within 22.5° east or west of south.	- operational energy for space heating.
		ii. Orient residential streets east-west.	

Neighbourhood Energy Conservation Checklist

Approach	Principle	Technique	Potential savings and benefits.
		iii. Where (ii) is not feasible, use angled lots, combined lots, flag lots, or key lots to ensure solar orientation.	
		iv. Where other techniques are not wholly successful stagger building setbacks.	
	b. Use flexible solar zoning regulations to ensure solar access.	i. Base solar zoning regulations on a performance standard: for example, major areas of glazing in 75 per cent of all dwelling units should be oriented within 22.5 degrees east or west of south and unobstructed between 09:00 and 15:00 hr during the heating season.	- flexibility of design.
		ii. Ensure neighbouring structures or trees do not infringe on solar access.	

CHAPTER 4

RESIDENCE - LEVEL APPROACHES

The greatest reductions in energy use at the level of the individual house and yard (excluding transportation energy) come from minimizing heat loss, and using more-efficient heating systems. The potential for residential energy savings will be considered in terms of the building envelope; the operation, design, and siting of the building; and the outdoor space planning (Figure 22).

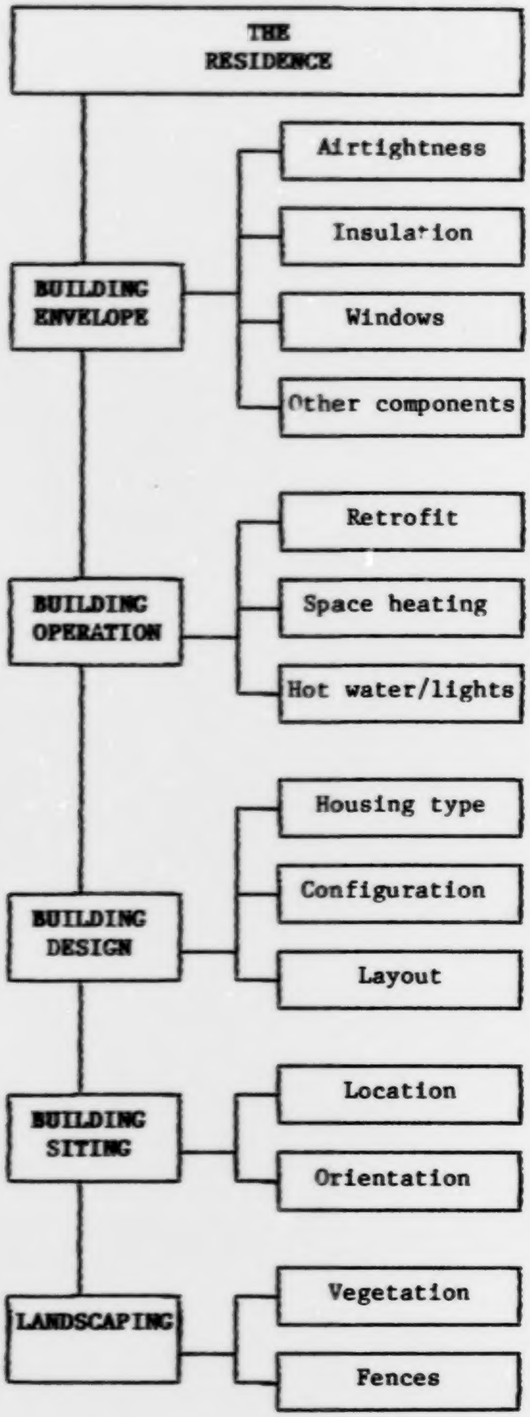
Increasing the airtightness and insulation of the building envelope is an effective way to save energy in housing. Improving the efficiency of heating systems in combination with improvement of the building envelope may be more cost-effective, especially when retrofitting existing buildings. Building design, siting, and landscaping can also produce significant reductions in residential energy use.

A multitude of energy conservation measures have been described in the popular literature where their reported costs and benefits are often misleading. Energy audits and life-cycle costing are tools that can help determine the cost-effectiveness of residential conservation measures. Energy audits determine the energy consumption of a residence and can be used to indicate the energy savings possible if certain conservation measures are applied, and relate those savings to total costs. The overall extent to which conservation measures can be applied economically is determined by life-cycle costing.

Life-cycle Costing

Life-cycle costing evaluates the total cost of a commodity (such as a building) over its assumed lifetime or a given amortization period, considering all operating costs, as well as capital and interest costs. Life-cycle costs may be used to determine the extent to which various conservation measures should be applied to housing, assuming the cost of the conservation measures, the cost of capital (discount rate), and the energy savings are known, and a given amortization period and increase in energy cost is assumed over the life of the project. Fluctuating interest rates and energy costs make accurate life-cycle costing difficult, yet they do not negate the importance of the technique in predicting the cost-effectiveness of energy conservation measures.

Figure 22. Opportunities for energy conservation at the residence level


THE RESIDENCE
BUILDING ENVELOPE
Airtightness
Insulation
Windows
Other components
BUILDING OPERATION
Retrofit
Space heating
Hot water/lights
BUILDING DESIGN
Housing type
Configuration
Layout
BUILDING SITING
Location
Orientation
LANDSCAPING
Vegetation
Fences

If a reasonable life-cycle (amortization period) is projected for a residence and the incremental capital costs for conservation measures are compared to the incremental energy savings projected for that period (assuming an increase in energy costs), the minimum life-cycle cost (capital plus energy) would occur when the incremental savings balance the incremental costs.

Some of the energy conservation techniques presented in this book are evaluated in terms of life-cycle costing using NEP projections for energy costs and an interest rate of 15 per cent; in many cases, however, the costs of the conservation measures were not available. The reliability of the projected energy savings in a number of examples is also questionable, since most are based on theoretical studies done before construction rather than on actual measurements.

Residential Energy Consumption and Conservation

The operational energy consumed by housing in a typical Canadian city is approximately 35 per cent of total municipal energy use. Of the residential total, about 75 per cent is used for space heating, 15 per cent for water heating, and 10 per cent for lighting and appliances.

Canada has one of the highest rates of residential energy use in the world. This is due not only to climate, but also to the widespread development of single-family detached housing and to the past availability of inexpensive energy. Compared to energy-efficient housing, most existing Canadian homes tend to be drafty, poorly insulated, and inefficiently heated. Past wastefulness means Canada now has a large energy-conservation resource.

More than 70 per cent of the housing units required in Canada to the year 2000 are already built. To develop their conservation potential, existing residences need to be better sealed and better insulated, and to have more-efficient heating systems to minimize the use of expensive, non-renewable fuels.

In existing residences, particularly, some energy conservation can be achieved through changes in personal habits. Lowering thermostats and wearing warmer clothing indoors, turning off lights, reducing water use, using energy-saving appliances, and timers for automobile block heaters are just some of the ways of reducing household energy use. For example, reducing the indoor temperature 5°C from 20 to 15°C cuts the annual space-heating requirement in Winnipeg, Manitoba, by 14 per cent. These, however, are generally temporary measures for conservation that can be used until more permanent solutions are implemented.

New housing should be built to high standards of airtightness and insulation; should have forms related to the climate and microclimate; and, whenever possible, should use locally available building materials to minimize embodied energy use. Space-heating energy should come from local, low-grade sources or alternative sources, rather than using high-grade (refined) fossil fuels or electricity. Low-grade energy sources include biomass fuels, waste heat from electrical generation or industrial processes, and solar energy.

BUILDING ENVELOPE

New energy-conserving housing saves energy mainly by isolating and insulating the indoor living environment from the fluctuations of outdoor climate. The building envelope acts like a thermos bottle to minimize heat loss through conduction, convection, and radiation in the heating season, or heat gain in the cooling season, and, thus, keeps the indoor living environment within the "comfort zone". The building envelope is comprised of the structure, air and vapour barriers, insulation, cladding, windows, and doors which enclose the indoor spaces. Making this envelope as airtight and as highly insulated as possible will provide the greatest savings in energy at the level of the individual residence.

Air and Vapour Barriers

Without first sealing air leakages, the application of other energy conservation measures is ineffectual. Air leakage, or infiltration, in an average dwelling unit is responsible for approximately one-third of the heating load. Care is required, therefore, in new construction or retrofit, to ensure proper installation of the air barrier and proper airtightness.

A vapour barrier is also required to prevent the moisture in interior air permeating and condensing within the thickness of the building envelope. Air and vapour barriers are often the same membrane, but this is not necessarily so. Tightly sealing a house may cause problems related to both high humidity and high particulate content in household air. Provision for controlled ventilation is the most effective way to deal with these problems. Air-to-air heat exchangers ensure an adequate supply of fresh air while transferring up to 75 per cent of the heat contained in stale exhaust air to incoming fresh air.

Insulation

Insulation increases the thermal resistance of ceilings, walls, and basements. The greater the temperature differential between the desired indoor comfort zone and the mean annual outdoor extremes, the greater the amount of energy required to keep the residence at the desired level of comfort. The thermal resistance of the building envelope plays a large part in the amount of energy that is lost in the form of heat or cooled air. Insulation requirements vary for different climates; therefore, pay-back periods for different amounts of insulation will also vary. In addition alternative insulation materials have different costs and benefits.

Windows

Careful planning of window orientation, type, and size as well as the use of shutters and awnings, can significantly reduce heat losses from windows in the heating season and heat gains in the cooling season. South-facing windows may also provide a net gain during the heating season.

Examples

Frankel/Lambert, Toronto, Ontario

The Frankel/Lambert Infill Study (Table 11) in downtown Toronto compared 3½ storey, stacked townhouse units built to Ontario Building Code (OBC) insulation standards (RSI 2.3 in ceilings and RSI 3.0 in exterior walls) to better-insulated but similar units, with RSI 5.3 in ceilings, RSI 4.0 in exterior walls, and RSI 1.8 in exterior walls below grade (Hix and Karl, 1977).

Whereas OBC units with north-south orientation had heating bills of $350 (1981 dollars) per year, the better-insulated units with the same orientation had heating bills of $284; saving 19 per cent per year due to insulation and reduced furnace size. The higher insulation levels would be cost-effective within a ten-year period assuming a 10 per cent interest rate and a 10 per cent escalation in fuel costs. Generally, sealing against air leakage and increasing insulation levels up to optimum levels are the most effective ways of conserving energy in new residences.

In this study, it was found that units oriented north-south had solar heat gains 45 per cent greater during the winter heating season than equivalent ones orientated east-west. This gain produced savings of 12.5 per cent in energy costs.

Double-glazed windows with insulated shutters were found to be more cost-effective than triple glazing, provided the shutters were kept closed a minimum of twelve hours a night in the heating season. The insulated shutters and double glazing were cost-effective in eight to nine years assuming a 10 per cent annual escalation in energy price. Insulated shutters reduced fuel

Table 11. Space-heating cost savings for Frankel/Lambert infill housing, Toronto

	Space-heating cost savings ($-1981)		Space-heating fuel cost per townhouse
	$	%	per year ($-1981)
Building Envelope			
North-south baseline			350
Insulation	66	19	284
Insulated shutters	77	22	207
TOTAL	143	41	234
Building Operation			
East-west baseline			399
Solar orientation	49	12	350
Heat pump with solar storage	59	15	291
Domestic hot water with solar storage	57	14	234
TOTAL	165	41	234

Source: Hix, 1977

costs by 22 per cent, from $350 to $273.

St. Lawrence Neighbourhood, Toronto, Ontario

The ECE Group (1978) projected an 18 per cent decrease in energy consumption in Phase B of the St. Lawrence Neighbourhood in Toronto. This would be achieved through ensuring the integrity of the air and vapour barriers in design and construction to control air leakage, through increasing insulation values to those recommended in Mesures for Energy Conservation in New Buildings (1978), and through orienting units so that more windows faced south.

The use of triple glazing was not recommended, because, whereas the costs and benefits of double-glazing could be amortized in under ten years, assuming a 10 per cent annual escalation in energy price, triple glazing would require sixteen years.

The St. Lawrence Neighbourhood researchers found that the pay-back period for insulated shutters would also be sixteen years, taking into account shutter hardware such as frames and locks, as well as the cost of visually relating the shutters to the building.

Energy Showcase, Saskatoon, Saskatchewan

The conserver homes in Saskatoon's Energy Showcase included a variety of insulation levels in double-wall, single-wall, and strapped-wall systems. Some of the conserver homes have super-insulated, 38 x 140 mm stud walls, impermeable-membrane air barriers, triple-pane windows, and air-to-air heat exchangers. Insulation is RSI 8.8 to 10.6 in ceilings, RSI 6.0 to 7.0 in exterior walls, and RSI 3.9 to 7.0 in basement walls.

The cost of these 102.2 m^2 low-energy houses was $2000 to $4000 per unit more than similar-sized conventional houses. The conventional houses used fibreglass insulation in 38 x 89 mm stud walls, polyethylene vapour barriers, and double glazing on all windows.

It was estimated that this level of investment in energy-saving features would save 50 to 90 per cent of the energy needed for space heating in equivalent conventional houses. Assuming the homeowner paid $3000 extra for the energy-saving features of the super-insulated house and that fuel price increases cancelled the interest on that investment, energy savings would total $525 annually for electrically-heated low-energy residences and $500 for oil-heated low-energy houses. The pay-back period for this investment is six years, whilst that for natural gas, at a saving of $200 per year, would be fifteen years.

Solar West, Vancouver, B.C.

The developers of Solar West in Vancouver estimated that they have achieved a 64 per cent overall reduction in energy use for space heating, water heating, appliances, and lighting, and an 81 per cent reduction in space-heating energy alone (Table 12).

Solar West was to have been a solar-demonstration community relying on both passive and active solar systems for space and water heating. This, however, was not possible without subsidies. Active solar systems would have increased the cost of each unit by as much as $10 000, while passive systems would have demanded major lifestyle changes, considered unacceptable in the marketplace. The solar approach was therefore modified in favour of more-traditional energy-saving features. These add about $4 000 to unit construction costs (3 to 5 per cent of total cost) and are expected to have a 5 to 10-year pay-back period.

The key energy-conserving measures include:

- caulking and weatherstripping
- insulation levels of RSI 6.7 in ceilings, RSI 3.5 in exterior walls, and concrete slab foundations insulated to a depth of 457 mm
- double-glazed windows
- forced-air gas furnaces with electronic spark ignition and continuous fan and flue dampers
- outside-air fireplaces with heat exchangers
- airlock entries at front and back doors, and
- family living areas generally on the south sides of units with large south-facing windows protected by eaves for summer shading, whereas bedrooms, utility rooms, closets, and bathrooms generally on the north side with north-facing windows.

The project is being monitored by the Champlain Heights Development Group with particular attention to problems of moisture build-up in airtight houses.

BUILDING OPERATION

The heating and cooling requirements of a building depend on its heat-loss characteristics, its micro-climate, and the amount of heat obtained from people, appliances, lighting, and solar gain. The cost of heating and cooling a building is directly related to the availability and cost of the energy source and to the cost and efficiency of the mechanical heating or cooling devices used. In the Canadian climate, space heating is generally of greater concern than space cooling.

Table 12. Space-heating cost savings in semi-attached housing with electric heat -- Solar West, Vancouver, B.C.

Item/ Description	Space-heating cost savings		Space-heating energy cost per unit per year ($-1981)
	$-1981	%	
Baseline			619
Airtightness	75	12	544
Insulation	235	38	309
Windows	98	16	211
Solar	91	15	120
TOTAL	499	81	120

Source: Moodie et al, 1979.

Although the prices of electricity and natural gas differ considerably between regions, the price of home-heating oil - as perceived by consumers - is relatively uniform, due to the federal oil-pricing policy. Opportunities for alternative energy use vary between energy zones (see Map 1).

Retrofit

In existing residences, where it is expensive or impractical to modify the building envelope substantially and where use of passive-solar and other alternative energy sources is constrained, the best alternative is to convert to the most economical form of energy available and to use the most efficient heating devices to convert the energy source to heat.

A cost-benefit analysis of the Saskatchewan Conservahome Program of energy retrofit emphasizes the importance of building envelope and heating systems in retrofit. The cost-effectiveness of this program is generally much lower than that of new energy-efficient homes. The amortization periods for retrofit range from 10 to 90 years depending on the characteristics of the existing houses. Some increments of retrofit, however, may be cost-effective even where the whole package is not. The most common worth-while retrofit measure is caulking and weather stripping to reduce air-leakage.

A residential energy audit can determine what conservation measures are cost-effective (i.e. have acceptable amortization periods) in a retrofit situation. The audit is a thorough review, by a qualified individual or team, of existing energy use and heat loss. The procedure is essential in establishing implementation priorities for energy conservation strategies. A residential energy audit collects data on the airtightness, insulation, operational heating efficiency, and energy expenditures of a residence and enters them on performance forms. These facts then allow a calculation of potential savings versus costs of retrofit measures, facilitating decision-making by homeowners.

Residential Solar Systems

Passive solar heating with a back-up mechanical heating system, or in conjunction with a thermal storage system, is an alternative to conventional heating methods. Passive solar heating requires south-oriented windows which catch the sun during the heating season and are shaded during the cooling season. The use of solar energy has an impact on the design and operation of housing, as well as their siting and orientation.

Passive solar space-heating systems (Figure 23) should be considered in conjunction with all other economic energy conservation measures. The contribution that solar energy can make to the reduction in the use of fossil fuel varies up to 40 per cent. The law of diminishing returns tends to mitigate against solar systems with very large (40 per cent and above) solar-heating contributions - the cost of capturing the additional energy becomes uneconomical.

The 1981-82 cost of a direct-gain passive system is in the order of 0 to 10 per cent (up to $6 000) of the cost of construction of the housing unit. Other passive solar systems such as Trombe and water walls will run 5 to 12 per cent ($3 000 to $7 200) of the cost of the housing unit. Direct-gain systems work most effectively when double-glazing is combined with night-time insulated shutters and additional thermal mass is incorporated with the building structure. Trombe and water wall systems require the construction of south-facing mass walls or water-containment systems behind glazing.

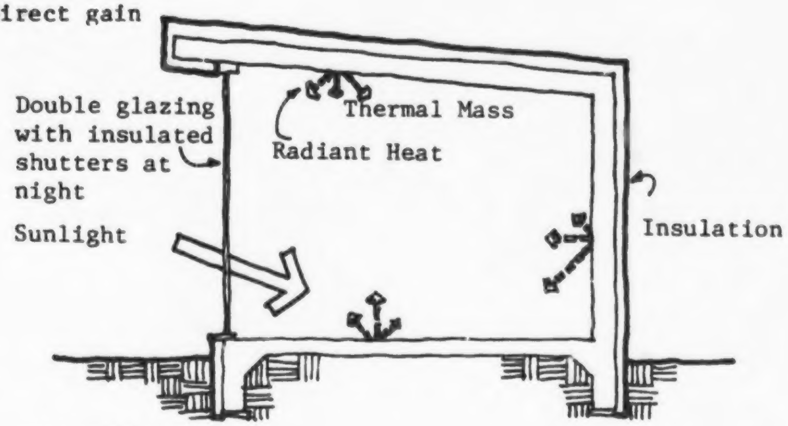
The Saskatoon Energy Showcase housing incorporated a number of passive solar systems, including Trombe walls, solariums, greenhouses, and various window arrangements. Beadwall windows and a number of other window insulation devices, such as shutters were used to prevent heat loss.

Active solar systems are less practical for space heating in Canadian climates. They can cost from $8 000 up, and pay-back periods range from 20 to 50 years or longer, at present energy prices. Since the relationship between the cost of the solar-heating device and the type of building on which the device is to be fitted is slight, multiple-family buildings with ten to twelve low-rise units may be the most economical application for active solar systems.

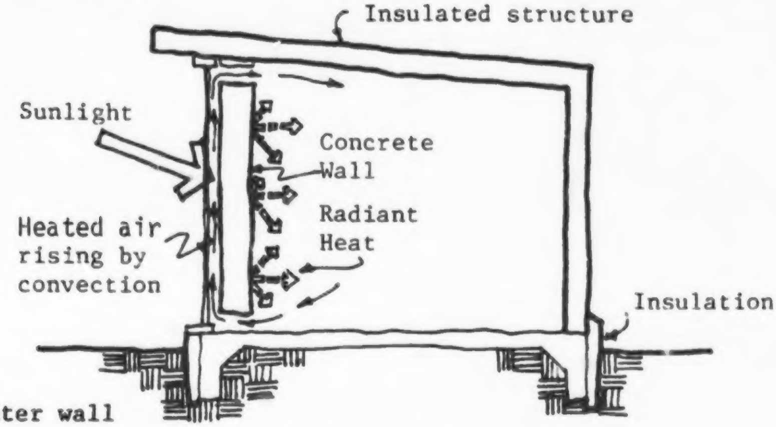
Between 15 and 20 per cent of the energy used in conventional residences goes toward domestic water heating. Solar domestic hot-water systems are more cost-effective in small buildings than active solar space-heating systems. The proportion of useful heat they deliver is greater because any increase in the temperature of inlet water to the hot-water tank will ease the load on the conventional domestic hot-water system throughout the year. Flat-plate solar panels costing approximately $3 000 can provide 50 to 75 per cent of an average family's hot-water requirement for a year. The average family spends $100.00 to $200.00 per year on hot water, so that the pay-back period for such a system would be 15 to 30 years.

Figure 23. Passive solar systems (Moodie *et al*, 1979.)

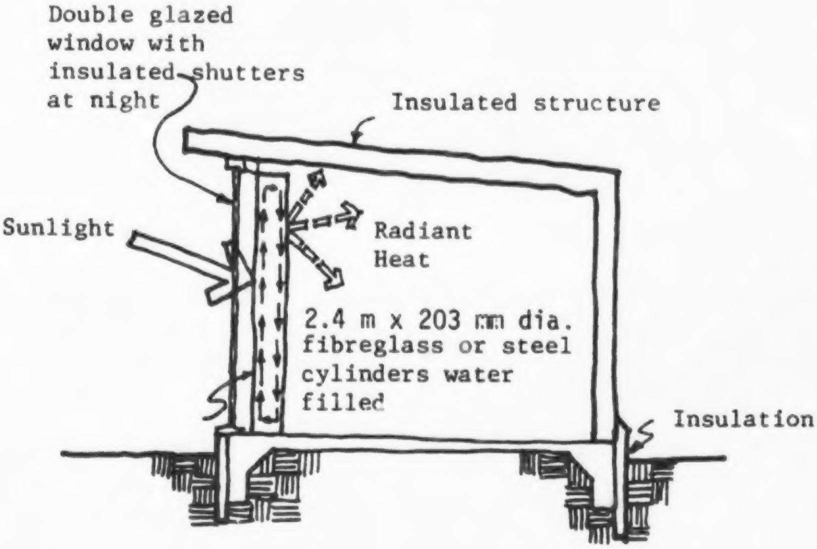
(a) Direct gain


Double glazing with insulated shutters at night
Thermal Mass
Radiant Heat
Sunlight
Insulation

(b) Trombe wall


Insulated structure
Sunlight
Concrete Wall
Radiant Heat
Heated air rising by convection
Insulation

(c) Water wall


Double glazed window with insulated shutters at night
Insulated structure
Sunlight
Radiant Heat
2.4 m x 203 mm dia. fibreglass or steel cylinders water filled
Insulation

BUILDING DESIGN

Building type, configuration, and layout considerations have a moderate impact on energy conservation.

Building Type

A row-house unit attached on both sides will use 33 per cent less of the heating energy used in a single-family detached bungalow of the same habitable floor area (Figure 24). Stacked townhouse units and walk-up apartments are even more energy efficient, using up to 40 per cent less of the energy used in a bungalow, as a result of the much-decreased ratio of exterior surface area to volume in the interior townhousing or apartment unit.

Although considerations of energy conservation favour higher-density building types, such as stacked townhousing (about 67 du/ha), the Canadian housing market still primarily demands single-family detached residences (about 12 du/ha). With this in mind, consideration of housing configuration and layout is important, especially in reinforcing other energy-conserving features in single-family housing.

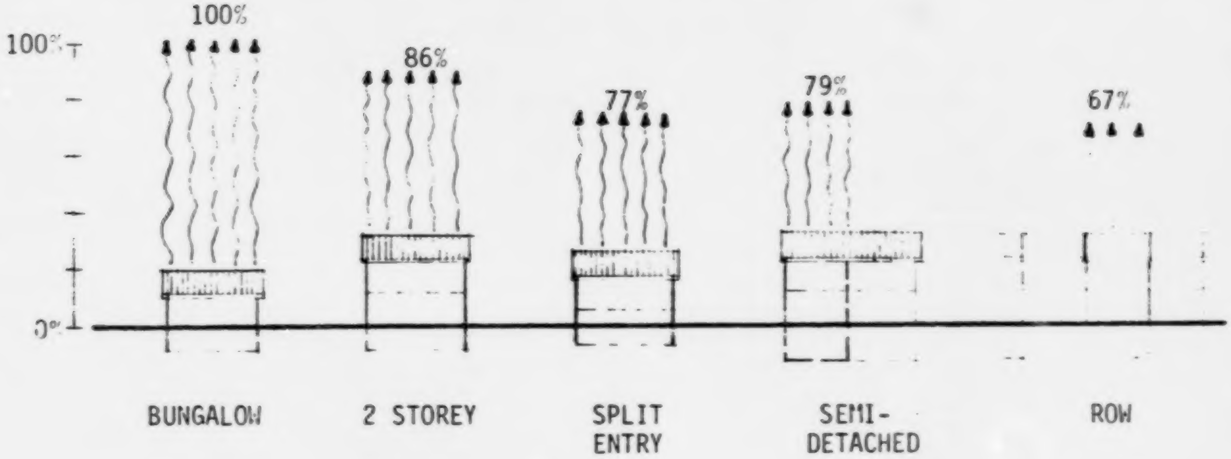
Building Configuration

Heating requirements can be reduced by using compact building configurations which are responsive to local climate. The physical characteristics of units with compact forms have the least ratios of exposed surface area to volume which minimizes the area for heat loss by conduction and radiation. Although a hemispherical dome has the least possible surface to volume ratio, it is impractical to build curvilinear forms using conventional building methods. With conventional construction methods, a cube provides the minimum ratio of surface area to volume. Two-storey houses with nearly square plans have been shown to use 14 per cent less of the energy required for single-storey rectilinear plans with the same habitable floor area. Sinking the cube partially below ground, as in split-level dwellings, will produce further savings through the extra insulation provided by the ground. Wholly underground houses with sun-trap courtyards are more practical in dry climates without snow than they are in the majority of Canadian situations.

Internal Layout

The layout of interior spaces also affects residential energy conservation. Locating active living spaces, such as living rooms, dining rooms, and kitchens, on the south side of the house where they can catch the sun, will reduce energy requirements for

Figure 24. Relative heat loss by building type (CMHC, 1980).



Note: Heat losses are shown as a percent of heat loss of the bungalow of same habitable floor area.

both lighting and heating. Bedrooms, storage, and utility spaces require less heating and can be used as a buffer zone on the cool north side of the house. Suitably sited attached or separate garages will buffer main living areas from cold winter winds. An air-lock entry or heated vestibule will also help minimize heat losses.

The magnitude of savings derived from careful layout of interior spaces, or consideration of building configuration, is not available, but is estimated to be small. Building form and layout must be responsive to building location, and building orientation for wind buffering and passive solar-energy collection.

BUILDING SITING

Properly locating and orienting a residence to consider winter wind buffering, summer cooling, solar gain, and solar shading will reduce energy use. The magnitude of such savings is a matter of debate.

The location of single-family housing should maximize solar access, minimize exposure to cold winter winds, and channel cooling summer breezes. Larger, multiple-family structures which are more energy efficient, on the other hand, may be used to buffer cold winds from other developments and may also be located in less favourable areas for solar orientation.

Where possible the orientation of a residence should maximize solar access. Single-family detached housing should be oriented so that the longest side and the longest roof area will receive the maximum solar radiation from the south.

The ideal orientation for solar access may vary slightly depending on the regional location of the house. Generally 15° east of south is an excellent orientation, providing maximum solar heat gain early in the day during the winter months and minimizing heat build-up in the summer (Figure 25). Any orientation which allows the largest surfaces of the house to be oriented to the south, as opposed to east or west, is beneficial (Figure 26).

Building setbacks are also important on conventional lots oriented north and south. If south-entry units do not have regular front-yard setbacks and north-entry houses do not have uniform rear-yard setbacks then certain houses will lose part of their solar access.

Figure 25. Solar orientation of a house.

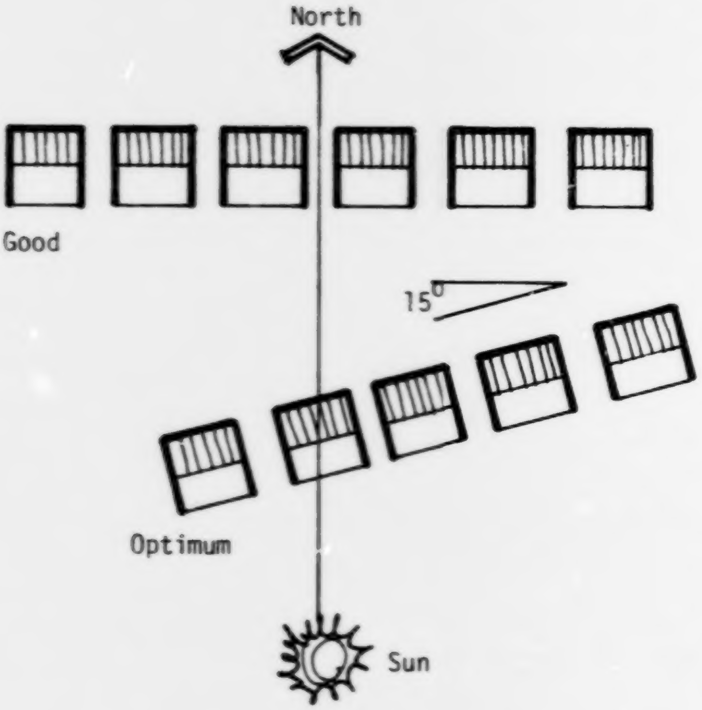
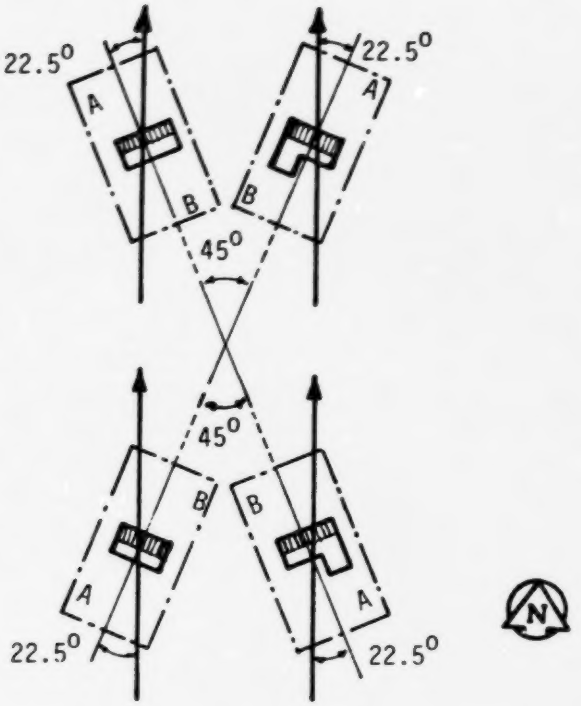

North
Good
15°
Optimum
Sun

Figure 26. Lot orientation criteria.


22.5°
22.5°
A
A
B
B
45°
45°
B
B
A
A
22.5°
22.5°
N

LANDSCAPING

The use of trees, ground cover, landforms, water, fencing, and auxiliary buildings can protect a residence both from winter heat loss and summer over-heating. Planting trees, shrubs, and grass and developing other landscaping for the purpose of energy conservation, however, is not cost-effective. If landscaping is done for other reasons, such as aesthetics, then the location, type, and quantity of vegetation should respond to energy conservation considerations.

Vegetation

Landscaping for energy conservation involves the use of land forms, vegetation, fences, and structures. Landforms, trees, and shrubs should be located so that a house will receive maximum protection from winter winds, maximum solar access, protection from the summer sun, and the benefits of cooling breezes. If a house is not protected, wind infiltration will create additional heating requirements in winter, and excessive solar gain will create additional cooling requirements in summer. A dense pine, reducing wind speed 85 per cent for a distance of 12 m leeward, decreases air infiltration into the protected house by 40 per cent (Figure 27).

Vegetation can also be used to reduce temperatures. Air temperature and radiation are about equal in their effect on human comfort. On a hot day, grass has a surface temperature 6 to 8 per cent lower than the air temperature, yet a street or concrete patio may have a surface temperature 25 per cent higher (Figure 28).

By reducing the velocity of the wind through frictional drag, a fence can reduce the air infiltration into a house. The cost of constructing a fence for the sole purpose of reducing air infiltration is, again, not economical. Similarly, auxiliary buildings can be used to divert airflow or to provide shade. Their location, however, must be carefully planned to maximize the energy savings and to prevent solar shading during the heating season, or snow build-up in circulation spaces during the winter.

RESIDENTIAL "KIT OF PARTS"

Improvements in the building envelope of existing houses, other than weather stripping and caulking, should be determined following a comprehensive energy audit to ensure their cost-effectiveness. Replacing old furnaces with more-efficient heating devices should also be based on the results of an energy

Figure 27. Saving energy by way of site design. (American Society of Landscape Architects, 1977).

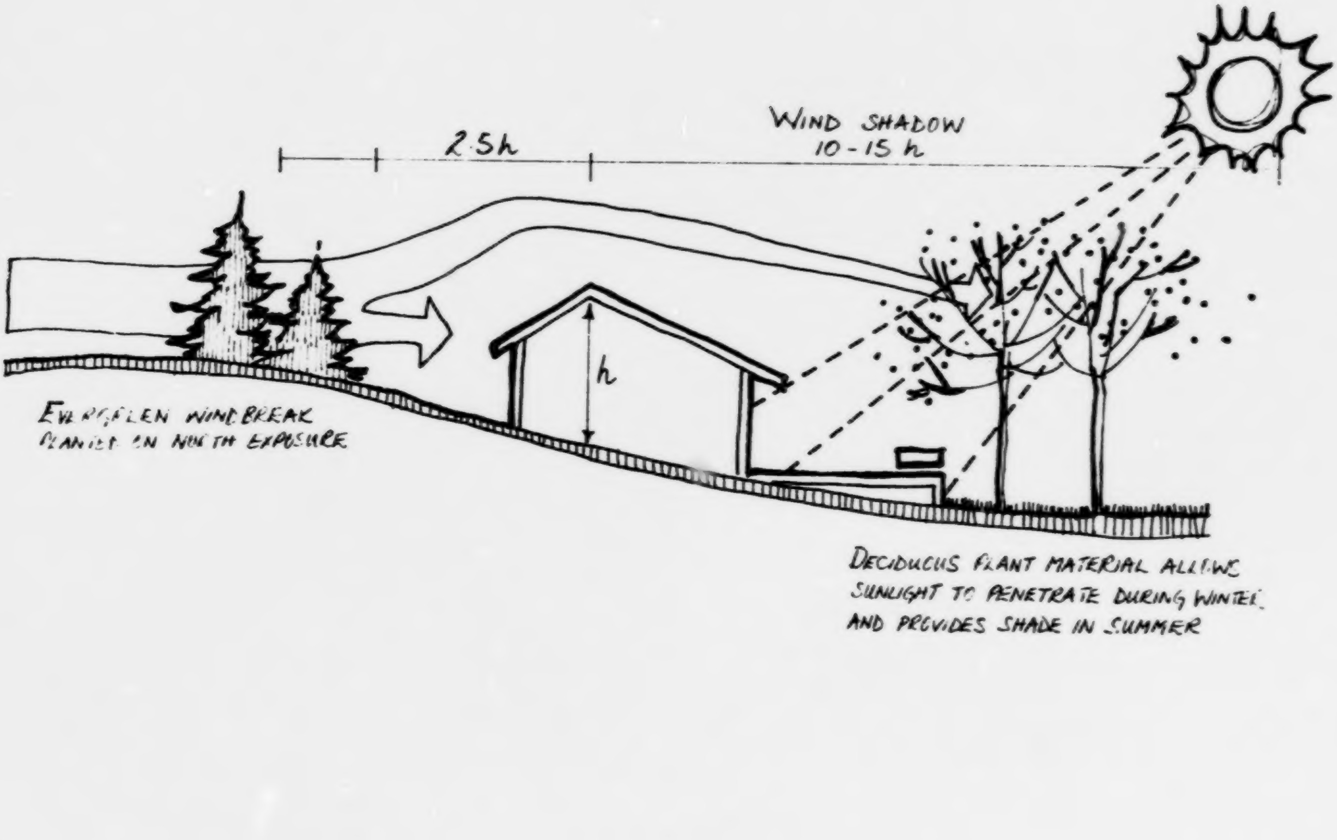
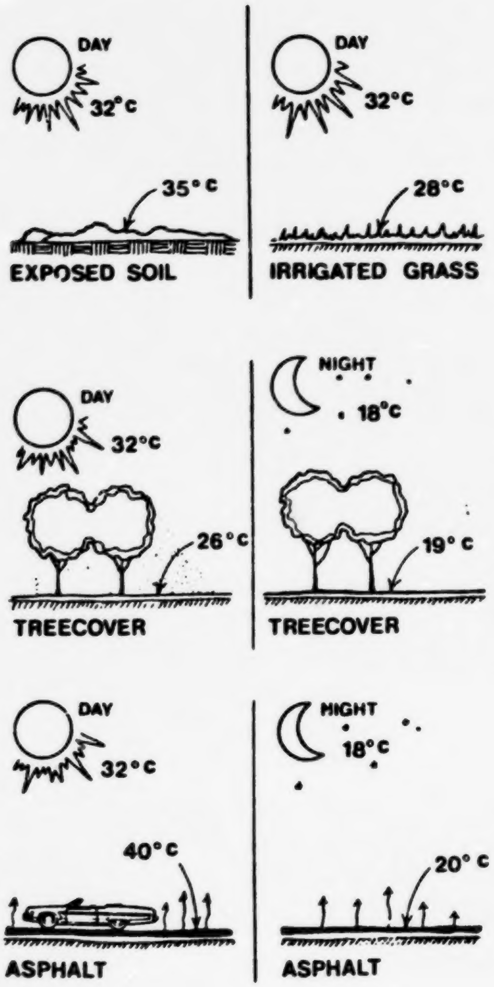

WIND SHADOW
10-15 h
2.5h
h
EVERGREEN WINDBREAK
PLANTED ON NORTH EXPOSURE
DECIDUOUS PLANT MATERIAL ALLOWS
SUNLIGHT TO PENETRATE DURING WINTER
AND PROVIDES SHADE IN SUMMER

Figure 28. Comparative temperatures. (American Society of Society of Landscape Architects, 1977).


DAY
32°C
35°C
EXPOSED SOIL
DAY
32°C
28°C
IRRIGATED GRASS
DAY
32°C
26°C
TREECOVER
NIGHT
18°C
19°C
TREECOVER
DAY
32°C
40°C
ASPHALT
NIGHT
18°C
20°C
ASPHALT

audit and should consider the life cycle of existing equipment and the proposed new equipment.

Energy conservation choices in new residences will greatly depend on the design of new neighbourhoods. Neighbourhood density and compactness will influence residential building type and configuration. District heating, passive-solar design, and wind buffering at the neighbourhood level will affect the thermal requirements, design, and siting of new residences, as well as the landscaping of private outdoor space. Heating systems should not be overdesigned or cost will exceed benefits. Building design and siting should consider neighbourhood microclimate, solar and wind exposure, shading and buffering, temperature, and precipitation. Space heating and cooling and water-heating requirements in residences should use the most efficient energy sources available.

Residential landscaping may be integrated with an overall neighbourhood concept for energy conservation. Landscape conservation principles can be applied to both existing and new residences.

The following summary represents a "Kit-of-parts" for residential energy savings. Not all "parts" apply to every situation. The energy savings associated with different techniques may vary considerably, depending on many variables.

Building Envelope

1. Residences should be made as airtight as possible through the careful installation of air barriers, caulking, and weather stripping. Up to 33 per cent of the residential heating load may be reduced in this way.

2. Tightly sealed residences should use air-to-air heat exchangers to ensure a fresh air supply, save heat loss, and control excess condensation.

3. Residences may reduce space-heating energy requirements for 15 to 75 per cent through increasing insulation levels in conjunction with airtightness. Insulation requirements will vary between energy zones and depend on the heating system to be used.

4. Windows should be oriented away from prevailing winter winds and toward the winter sun, with proper summer shading. This normally implies minimizing north-facing glazing and maximizing south-facing glazing. Also, westerly orientations, which are hard to protect from excessive summer heat gain, should be avoided. Proper window orientation can

save 10 to 40 per cent of space-heating energy requirements.

5. The economics of choosing single, double, or triple glazing will vary, depending on the type of project and location. Double glazing on the south side and triple glazing on the north side of a residence is economical in 1982, in most parts of southern Canada.

Building Operation

6. Retrofit decisions should be based on an energy audit.

7. Space heating should use the most efficient and least expensive available energy system. This will vary depending on the energy sources available in a given area.

8. Where natural gas is available, heating efficiencies may be increased by 25 to 50 per cent using new furnace technologies.

9. Use of "add-on" hybrid systems - oil furnaces and heat pumps, for example - will save energy and cost in retrofit situations or where oil is the least expensive fuel.

10. The cost-effectiveness of passive solar systems is affected by a number of factors, including neighbourhood design and the thermal efficiency of the residence. Passive solar can supply 10 to 40 per cent of space-heating needs.

11. Measures to save energy in heating water can theoretically save up to 15 per cent of total residential energy demand.

12. Increasing the efficiency of day lighting can save electrical energy. The magnitude of savings is small and will depend on latitude, building siting, and orientation.

Building Design, Building Siting, and Landscaping

13. Higher-density building types use up to 40 per cent less energy than single-family detached houses. Row housing uses 33 per cent less of the space-heating energy required by a detached bungalow; semi-detached housing uses 21 per cent less.

14. Building configuration also affects heat loss. Two-storey houses with square plans will use 14 per cent less than required for those single-storey with rectilinear plans. Split levels will use 23 per cent less of the space-heating required for similar-sized bungalows.

15. Buildings designed to channel cold winds away from the structure will save energy.

16. Residences designed with those internal spaces that require less heating (such as storage areas and bedrooms) as buffers on their windward sides, not only take advantage of the sun in living spaces such as family rooms, living rooms, and dining rooms, but also will save energy. Use of air-lock entries will also save energy. The amounts saved, however, will be small.

17. Residences should be oriented so as to minimize exposure to cold, winter winds and maximize exposure to winter sun. Generally, orientations of up to 22.5 per cent east or west of south will provide substantial opportunities for gaining solar heat. Residential orientation is often dependent on the neighbourhood layout of streets and lots.

18. Residential setbacks should be coordinated within a development to maximize the potential of solar-heat gain in winter. This implies fairly uniform setbacks on lots oriented north to south and a varied setback to catch the sun for part of the day on lots oriented east to west.

19. Land forms, trees, fences, and auxiliary buildings should be organized to minimize the exposure of a residence to cold winter winds and hot summer sun, while not interfering with solar access. These landscape elements may also be used to channel cooling summer breezes.

CHAPTER 5

CONCLUSIONS

This overview of energy conservation and residential land use has focused on the costs and benefits of energy conservation at the levels of the city, neighbourhood, and residence. A number of approaches have been put into perspective and their potential energy savings analysed where possible.

While recognizing that energy conservation is of national importance, and part of the federal government's strategy to achieve energy security, economic benefits will remain the primary incentive for government, private industry and individuals to conserve energy. Those conservation approaches which provide the greatest savings with the least costs should be pursued first.

Due to future variability in energy prices and inflation, the use of lifecycle costing is essential for projecting the cost-effectiveness of any conservation measure. In some circumstances conservation measures will be undertaken now, even if they are not cost-effective in simple payback terms, in order to save energy in the future.

The three scales of residential land use - the city, the neighbourhood and the residence - have served to separate the principal conservation issues into manageable groupings, each with a major point of focus. Energy conservation principles that are cost-effective fall into the following areas. Firstly, the organization of land uses to produce energy savings, primarily through reductions in embodied energy requirements for roads and utilities, and reductions in operational energy requirements for transportation. Secondly, environmental design to save embodied energy and operational energy for space heating and cooling, and the use of district heating and passive solar to reduce conventional energy use. Finally, the building envelope, operations, design, siting and landscaping can be modified to reduce space heating and cooling energy requirements.

These principles are interrelated. Which are most applicable to a given situation depends on factors such as marketability and development regulations, as well as the energy requirements and opportunities of the relevant energy zone. Developers and planners should select those conservation principles which fit the development context, applying techniques which are compatible and which are most suitable to the local context.

The major relationships between the conservation principles at the city, neighbourhood and residence levels are:

- density and district heating;
- density and building design;
- district heating and building envelope;
- district heating and building operations;
- environmental design and building design;
- environmental design and building siting;
- environmental design and building landscaping;
- environmental design and passive solar;
- passive solar and building envelope;
- passive solar and building design;
- passive solar and building siting; and
- passive solar and building landscaping.

Many interventions to conserve energy will require massive and concerted efforts by both the public and private sectors. Some require significant changes in lifestyles, for example, giving up the single-family detached house with a private yard in favour of higher density accommodation, and using public transit instead of the private automobile. Others may require significant changes in conventional approaches, for example, developing performance standards for solar access in subdivisions or developing construction practices which ensure adequate insulation and proper installation of air barriers.

While not all providing the same magnitude of energy savings, measures from among the following sets of actions are most likely to produce the best balance of costs and benefits in existing and future urban areas, in various Canadian environments:

Existing Areas

1. Encourage development in existing built-up areas through development plans, zoning by-laws, and incentives;

2. Develop attractive and energy-efficient public transportation systems;

3. Increase densities to a level of about 67 du/ha wherever possible through encouraging higher density redevelopment, rehabilitation, conversion, and infill;

4. Mix land uses through strategies and zoning by-laws which encourage cottage industry, and local commercial and transit-oriented development;

5. Develop district heating systems in conjunction with garbage incineration and cogeneration of electricity in areas where

population size and density make such systems viable;

6. Retrofit existing housing based on energy audits to determine the principal areas and optimum levels of expenditure on energy conservation. Retrofit will likely concentrate on improving the airtightness, insulation, and the efficiency of heating and cooling devices in a residence.

New Development

1. Ensure development is contiguous with existing built-up areas and located to minimize the embodied and operational energy used for transportation and utility infrastructure and to minimize the amount of urban development on good agricultural land;
2. Develop higher densities and mixed land uses to create pedestrian, bicycle, and public transit-oriented developments;
3. Use district heating where appropriate;
4. Apply environmental design principles to ensure that the development is taking the best advantage of site opportunities and minimizing the effects of site constraints;
5. Ensure that a maximum number of units are oriented for solar access through the proper alignment of streets, lots, and buildings;
6. Develop conserver houses with optimum levels of insulation, airtightness, and window glazing, oriented to take advantage of the sun's energy;
7. Use higher density, compact housing forms with internal layouts responsive to the external environment;
8. Use optimum combinations of heating systems and envelope thermal efficiency;
9. Where developing landscaping as an amenity, base decisions on conservation criteria.

If the standards of energy efficiency characterized by existing low energy homes in Vancouver and Saskatoon were applied, with regional sensitivity, to all future residences in Canada, significant reductions in the overall amount of energy used in this country could be achieved. The problem is to persuade home buyers to spend the extra money on conservation and to convince developers and home builders that they will do so. There is a need to encourage cost-effective energy conservation in new housing and the retrofit of existing housing which will save energy, reduce dependence on conventional fuels, and move Canada closer to energy self-sufficiency.

This country has a wide range of energy opportunities, both conventional and alternative. Energy conservation is the cornerstone for the reduction of immediate energy requirements, giving Canada time to develop new energy sources.

APPENDICES

Appendix I. Climatic data for Burke Center

General: Continental climate

Degree days	
Heating	2766 HDD
Cooling	504 DDC
Average temperature:	
Yearly	12.1°C
Winter	0.6°C
Summer	27.8°C
2.5 per cent design temperature:	
Winter	7.2°C
Summer	32.8°C dry bulb and 23.3°C wet bulb
Average wind velocity:	
Winter	16 km/h (NW)
Summer	13 km/h (W-S)
Average rainfall:	89 cm/yr
Average snowfall:	61 cm/yr
Solar gain	402 kJ/m^2/day

Annual average sunshine: 2 280 hr
(52 per cent of possible)

Source: Urban Land Institute (1981).

Appendix II. Project data for Conventional Plan of Burke Center

LAND-USE INFORMATION

Site area: 563 hectares

Dwelling units:

Completed....................................	1 500
Total planned................................	5 452

Gross density: 9.7 du/ha

Parking

Each dwelling (including garden and mid-rise units) has two off-street parking spaces. (1)

LAND-USE PLAN

Land Use	(ha)	(%)
Residential	423	73
Industrial	25	4
Commercial	21	4
Schools	6	1
Major open space (2)	88	16
Total	563	100

ECONOMIC INFORMATION

Site cost: Approximately $23 475/ha
Site improvement cost: $25 000 000 (3)
Construction cost: $215 to $376/m^2 (4)
Amenities cost: $550/unit (5)
Homeowner association dues: $240/yr (6)

Appendix II (cont'd). Project data for Conventional plan for Burke Center

RESIDENTIAL UNIT INFORMATION

Unit Type	No.	Unit size (m^2)	Lot size (m^2)	1980 Price in 000s
SFD	1 193 (7)	167 - 279	520 - 743	$71 - 134
Patio/Duplex	2 450 (8)	111 - 204	371 - 743	63 - 89
Townhouse (9)		102 - 204	279 - 650	58 - 90
Garden (10)	1 509			
Mid-rise (10)	300			

NOTES:

1. Standard required by Fairfax County.
2. Includes the major open space and stream valley system. Additional open space is contained in the above gross parcels, bringing the total to about 121 hectares.
3. Includes planning, engineering, streets constructed by developer, grading for these streets and for amenities, and water and sewer lines to finished lots and to parcels in which unfinished lots are sold.
4. Varies widely because of the different builders involved.
5. This fee paid by builders to Burke Center Partnership includes all amenities and recreation development.
6. Includes use of all community-wide open space, administration, and garbage collection, but not private street and cluster open-space management.
7. The 520-m^2 lot fronts on a 21.3-m private street space and backs on a 12.2-m wooded common buffer.
8. Includes units under "Townhouse," the following item in the table.
9. Townhouse units are included in total for "Patio/Duplex", the preceding item.
10. As of this study, no garden or mid-rise apartments have been constructed.

Source: Urban Land Institute (1981).

Appendix III. Project data for Radisson

RESIDENTIAL UNIT INFORMATION

Type	Unit Size (m^2)	Lot Size (m^2)	Number	Lot Price	Sales Prices
Single-family Detached	134- 212	836- 1022	135	$12 000	$71 000 90 000
Townhouse	128	418	66	1000	45 000
Multi-family	-	-	142	-	-

DEVELOPMENT CHARACTERISTICS OF RESIDENTIAL STUDY SITE

	Conventional plan	Energy plan #1	Energy plan #2
Total number of dwelling units	201	259	220
Gross site density (units/ha)	6.35	8.15	6.92
Unit distribution:			
Single-family detached	135	—	116
Single-family cluster	—	132	32
Townhouse conventional	66	—	72
Townhouse cluster	—	127	—
Total No. of protected units	64	193	168
Public road length (m)	2804	2377	2652
Private roadways (m)*	533	1228	671

* Private roadway includes pavement for flag lots on conventional plan, as well as cluster housing.

Appendix IV. Climatic data for Radisson

General: Humid continental

Degree days

Heating................................	3692 HDD
Cooling................................	288 DDC

Average temperature:

Yearly................................	8.9°C
Winter................................	2.8°C
Summer................................	21.7°C

2.5 per cent design temperature:

Winter................................	-17.8°C
Summer................................	32.2°C

Average wind velocity: 15.9 km/h ranging over a 60° north/northwest arc (in winter)

Mean rainfall:	92.5 cm (1)
Solar gain:	300 Langleys

Annual average sunshine:
November through March -- less than 40 per cent
May through August -- up to 65 per cent

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1. Rainfall is distributed evenly throughout the year, averaging about 7.6 m per month. On about 168 days a year, precipitation exceeds 0.025 cm. The mean annual snowfall is 254 cm and monthly amounts in excess of 61.0 cm are not uncommon.

Appendix V. Summary of income per lot for Radisson

Item/Description	Conventional plan	Energy plan #1	Energy plan #2
Number of dwelling units	201	259	220
Income per lot type:			
single-family	$1 620 000 (135)	$1 584 000 (132)	$1 776 000 (148)
townhouse	$ 396 000 (66)	$ 762 000 (127)	$ 432 000 (27)
Total site income	$2 016 000	$2 346 000	$2 208 000
Average income per lot	$ 10 029	$ 9 057	$ 20 036
Total site income increase	(n.a.)	$ 330 000	$ 192 000
Profit per lot increase	(n.a.)	$ 1 274	$ 872

ECONOMIC INFORMATION

Site Cost:	$1235/ha (1968) $2471/ha (1979)

Site improvement costs: approximately $9 600/unit (conventional)

Construction costs: $125/m^2 (residential)

GLOSSARY

active solar system. A heating or cooling system that requires mechanical devices to move the collected solar energy.

alternative energy sources. This term is used to differentiate energy technologies which are not yet in general residential use from conventional technologies related to fossil fuels, hydro-electric power, and nuclear fission. Their energy sources are either renewable, such as solar, wind, biomass, geothermal, and tidal, or almost inexhaustible, such as nuclear fusion.

angled lot. A lot with side lot-lines that do not meet the street at a right angle.

berm. A man-made mound of earth, used as a free-standing wind-break or noise barrier. When placed adjacent to buildings, it provides a means of increasing thermal resistance of the building envelope.

biomass. Any organic matter available on a renewable basis, including agricultural crop waste, wood and wood waste, animal wastes, municipal waste, and aquatic plants.

cogeneration. The production of thermal energy and electricity in combination, whereby the waste heat from producing electricity is recovered and used. Cogeneration provides a higher overall cycle efficiency than generation of electricity and heat separately since the same energy source is used to provide more than one service.

conventional energy sources. These are energy sources generally used for residential space heating, water heating, lighting, and appliances; they include fossil fuels, such as natural gas, oil, and coal; hydro-electricity; and nuclear power.

cost effective. Measures which are cost effective have short pay-back periods or a good ratio of benefit to cost.

degree day. A measurement of the relative severity of an area's heating or cooling season; a degree day is equal to each one degree Celsius deviation from the reference point of 18°C in the mean daily outdoor temperature. Thus a mean daily outdoor temperature of 10°C represents 8 heating degree days, while a mean daily outdoor temperature of 23°C represents 5 cooling degree days. Unit is degree day Celsius.

design temperature. That temperature representing the lowest expected for a location and used in determining the design heating load (the total heat loss from a building during the most severe winter conditions likely to occur).

district heating. A heating system that distributes heat through a medium, usually steam or hot water, in pipes to individual buildings from a central plant. Some district heating systems use waste heat recovered from electricity production, incineration, or industrial processing.

double glazing. A system of two separate layers of glass or plastic used to create an insulating barrier in windows, skylights, greenhouses, and solar collector coverings.

embodied energy. The amount of energy expended to manufacture and put building and infrastructure materials (and systems) in place.

energy audit. A tool used to determine how efficiently energy is being used. In a residence, a review of energy use and heat loss permits the owner to make decisions about the most cost-effective means of reducing energy use. In a city, it is a review of total energy use, including embodied and operational energy, to determine where savings are possible.

heating season. The period in which additional heat is required in a residence to ensure personal comfort. The winter heating season in Canada ranges from moderately short on the West Coast of British Columbia and in Southern Ontario, to very long in the Arctic. Heating degree days provide an indication of the length and severity of the heating season.

heat pump. A space-conditioning unit that cools like a conventional air conditioner or refrigerator by removing heat from the inside air and delivering it to outside air but that, in reverse, heats by removing heat from outside air and delivering it to the interior. Air-source heat pumps are most common but heat pumps can also exchange energy with a water body. Although gas-fired heat pumps are commercially available, heat pumps are usually powered by electricity. Electric heat pumps are an efficient use of electricity since it is possible to obtain 2 to 3 times the heat output for the same electric input as in conventional electrical resistance heating.

infiltration. The uncontrolled air leakage into a building, usually expressed as the number of air changes per hour of an air volume equal to the interior space.

insulation. A material or system that is used to retard heat loss or gain.

joule. A unit of energy, J, equal to one N.m (newton-metre)/sec^2 and 10^7 ergs.

langley. A unit of solar radiation equivalent to one gram calorie per square centimetre of solar illuminated surface.

life-cycle cost. A measure of the total cost of a system over its expected lifespan to include initial production, maintenance, repair, and operating costs. The accumulation of costs over the life of the system reflects the relative value of money over time (discounting future costs to present value).

low-energy housing. Housing with very low levels of energy demand due to careful consideration of all factors related to heat loss and power wastage.

Mb/d. Million barrels of oil per day, or the primary energy equivalent.

OPEC. Organization of Petroleum Exporting Countries.

operational energy. The amount of energy expended in space heating and cooling, lighting, running appliances, transportation, and operating and maintaining services.

passive solar system. A heating or cooling system that requires no mechanical devices to capture, store, and use collected solar energy.

pay back. A measure of the economic viability of a project or system; usually defined as the number of years required to accumulate savings which exactly equal the initial capital cost of the system. Pay back does not give an accurate portrayal of the system's total life-cycle value.

performance criteria. Standards related to the needs of people and the use of the environment that do not involve rigidly measured elements.

primary energy production. Refers to energy production from crude oil (both conventional and synthetic), natural gas, natural gas liquids, coal, hydro-electricity, and nuclear-electricity.

retrofit. The addition of new energy-related technology to an existing building.

RSI. The metric measure of thermal resistance, or the tendency of a material to retard the flow of heat. RSI is the reciprocal of a material's thermal conductivity or 1/joule per second per m^2 per °C.

secondary energy consumption. Refers to energy actually consumed in a given region of Canada, including that for space heating, running appliances and automobiles.

thermal mass. The potential heat storage capacity in a substance, system, or building; usually used in reference to common building materials (concrete, masonry, and adobe walls) and passive solar design (water drum walls, Trombe walls).

Trombe wall. A passive solar collector, named after the French designer Felix Trombe. South-facing glazing through which the sun's rays travel is built close to a large dark thermal mass, usually a thick concrete or masonry wall with vents or water-filled barrels painted black. In the coldest months, air in the space between glazing and mass is heated during the day. As it warms, the air rises through vents in the top and flows into the living quarters. Cooler air that is near the floor of the living quarters is pulled into the air space through the bottom vents to be heated. Throughout the day, this convective process continues. At night, the mass, which has stored a significant amount of thermal energy, releases heat into the living quarters via radiation. In the warmer months, the Trombe wall system can theoretically cool a building. Unfortunately, the wall itself tends to overheat and may add too much thermal energy to the structure if unwanted heat is not vented to the outside. In such cases, shutters or shades may have to be placed over the Trombe wall glazing in the summer.

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